

**ECONOMIC POLICY AND RESOURCE IMPLICATIONS OF BIOFUEL
FEEDSTOCK PRODUCTION**

A Dissertation

by

NAVEEN CHANDRA ADUSUMILLI

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

AUGUST 2012

Major Subject: Agricultural Economics

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ABSTRACT

Economic Policy and Resource Implications of Biofuel Feedstock

Production. (August 2012)

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Dramatically higher fuel prices and massive petroleum imports from politically unstable countries have contributed to a major national initiative to generate renewable fuels in the United States. Often, such policies are enacted and implemented with huge taxpayer expenditures without due diligence to the consequences.

The evaluation of the water quality impacts of converting pastureland to intensive biomass production for fuel in a southern Texas watershed suggest significant increases erosion and nutrient loadings to water bodies. The Best Management Practices (BMPs), cover crop and filter strips when implemented individually failed to produce status-quo reduction levels. Combined BMPs implementation produced improved mitigation, at substantially higher costs, highlighting the issue of sustainability related to the economics of renewable fuels.

The estimation of the net energy of biomass ethanol accounting for the production input data indicate a greater than one energy return for biomass crops. However, the policy results indicate that only 70 percent in net contribution to the

energy supply is achieved due to relatively lower energy returns compared to conventional fossil fuels. In addition, because the ethanol produced has to have the energy used deleted from the total, the cost of producing a gallon of biomass ethanol is substantially higher than that of gasoline.

The impacts of an exogenously-specified biofuel mandate fulfilled by the production of a dedicated biomass crop and its consequent effects on commodity prices and overall welfare are estimated. Net farm income increased due to an increase in crop prices; however, both consumer surplus and total surplus decreased. The analysis is extended to estimate the sensitivity of Conservation Reserve Program (CRP) acres returning to crop production and the potential of higher biomass yields. The results indicate that net farm income decreased and consumer surplus increased due to a decrease in crop prices, resulting in an increase in overall welfare.

This current research evaluates the unintended consequences of the U.S. energy policy and provides interesting insights of the potential economic and environmental impacts. These results suggest policy makers should be cautious before enacting energy policy and consider multiple alternative energy sources in an economic and financial context to achieve a sustainable energy goal.

DEDICATION

To my family

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1. INTRODUCTION

With concerns over increasing energy use, the Energy Independence and Security Act (EISA) of 2007 was implemented mandating a Renewable Fuel Standard (RFS) target of 36 billion gallons by 2022, including cellulosic ethanol (Renewable Fuels Association 2010a). Although the RFS calls for a large percentage increase in the use of renewable fuels, the 36 billion gallons remain a small proportion of the projected 264 billion gallons of energy use by the transportation sector of the United States by 2035 (U.S. Energy Information Administration 2010).

Often policies are enacted and implemented with huge taxpayer expenditures without due diligence to the unintended consequences. The biofuels demand triggers price increases by increasing demand for agricultural crops, shifting land away from food, fiber, and feed to feedstock for energy production. Such a shift in land toward energy crop production affects the supply of other grains and crops (Pimentel 2001). Some of the early studies that analyzed the effect of growing crops as feedstock for biofuels found that 12 billion gallons of biofuels production using grains and crop residues would increase food grain prices by 46 percent (e.g., Taylor 1978).

The U.S. Environmental Protection Agency reported that cropland due to biofuel production might be prone to pressures such as monoculture production, intensive application of nutrients, continuous cropping, and increased irrigation in an attempt to meet the RFS of 36 billion gallons (U.S. Environmental Protection Agency 2010).

Such production activities make land resources vulnerable to erosion and loss of productivity. In analyses carried out separately by Malcolm, Aillery, and Weinberg (2009) and Taylor and Lacewell (2009a), it was found that meeting the bioenergy production mandates would expand cropland requirements by 5 million acres by 2015, resulting in extending production to marginal lands, characterized mostly as being high-erosion prone and less productive (Farm Service Agency 2012).

Renewable fuels production is expected to increase demand for inputs, mainly fertilizers and consequently impact fertilizer prices. Expansion of biofuel production from the U.S. Department of Agriculture baseline of 15 to 35 billion gallons was estimated to increase nitrogen, phosphorous, and potassium fertilizers use and prices in the range of 6.0 to 9.0 percent (Taylor and Lacewell 2009a). These studies suggest that increased demand for inputs and associated higher prices are occurring because of expanded renewable fuels. Additionally, increased fertilizer use due to expanded and intensive crop production has the potential to lead to increased nutrient losses to surface and ground water, causing eutrophication and dead zones in the Gulf (Powers 2007).

Furthermore, ethanol does not appear to consistently achieve a net energy gain, as the energy required during the crop growth and conversion is often greater than the energy value in the ethanol (Pimentel and Patzek 2005). Summing up the national

energy implications, including the energy used to irrigate, fertilize, grow, transport, and convert, the energy balance for corn ethanol is estimated at 3.4 to 1 compared to 5 to 1 for gasoline (Rapier 2007). As a result, gross production of 36 billion gallons of renewable fuel would represent a net increase of only 25.4 billion gallons of fuel (Adusumilli et al. 2010), suggesting that the resulting U.S. biofuel supply will be much less than the production mandates. Since the 1970s, there have been numerous studies and reports discussing effects of alternative proposed biofuel policies as well as analyses of implemented energy policies (Taylor 1978, Taylor and Lacewell 2009a). With U.S. petroleum use exceeding 300 billion gallons in 2008, coupled with concerns over share of imports exceeding 70 percent (U.S. Energy Information Administration 2010) attention has been refocused toward development of renewable fuels. However, critics fear similar issues such as increase in crop prices, input prices, and decrease in overall welfare tend to rise with production of biomass crops and the associated renewable fuels.

The research is divided into three sections, with each section composed of a stand-alone academic paper. The common theme occurring throughout the three papers addresses the issues surrounding a national energy policy that is focused on improving energy independence through production of domestic fuel from natural sources such as crops and woody biomass. The chapters range from a pilot study for a farm level analysis in South Texas addressing the implications of converting pastureland to biomass crop production with policy implications to mitigate water quality impacts, to a net energy estimate for the farm level analysis to identify the net contribution of biofuels to the U.S. energy supply and the consequent impact on cost of production of biofuels,

expanding to a national analysis viewing the macro implications of the RFS related to biomass feedstock. The results are of value to decision and policy makers.

1. The first essay is developed using the Soil Water Assessment Tool (SWAT) to evaluate the production of a biomass crop for fuel in a southern Texas watershed and its impact on the water quality along with the implications of Best Management Practices to protect the water quality in the watershed. Economic costs and policy implications to mitigate potential environmental damages are addressed. A goal of this study was to internalize the negative externalities in the form of water quality damages.
2. The second essay is focused on estimating the net energy of biomass crops produced to supply feedstock to a 30 million gallon ethanol conversion plant in Middle-Gulf Coast, Edna-Ganado, Texas. The energy inputs account for the factors involved including production, harvesting, hauling, and processing of biomass to ethanol from McLaughlin (2011a). The unit of analysis is a gallon of ethanol, i.e., the energy required to produce a gallon of ethanol is compared against the energy content in a gallon of ethanol. The energy balance estimate is then used to evaluate policies such as net supply contributed by biofuels and the consequent impact on cost of production of biofuels.
3. The third essay is an analysis applying the Agricultural Simulation Model (AGSIM) to evaluate the potential aggregate effects of production of biomass for fuel at a level to meet the RFS related to cellulosic feedstock. The model is configured to evaluate the effects of producing the biofuel mandates on prices of

commodities, fertilizers, cropping pattern shifts, trade balance, government expenditure, and consumer and producer surplus. For this analysis, it is assumed that the biomass feedstock is a dedicated crop that competes for existing cropland. The analysis is extended to consider the potential implications of conversion of CRP acres to cropland and availability of higher biomass yield crops as biofuel feedstocks.

2. IMPLICATIONS OF CELLULOSIC BIOFUEL CROP PRODUCTION ON WATER QUALITY AND EVALUATION OF MITIGATION MANAGEMENT PRACTICES IMPLEMENTED AT WATERSHED SCALE IN TEXAS

2.1 Introduction

United States energy policy that focuses on reducing foreign oil dependency and meeting the increased fuel demand by the transportation sector has prompted the nation to renew its interest in alternative fuel sources, mainly ethanol, produced from crop grains and biomass. Recent legislative developments supportive of alternative fuels include the Energy Policy Act of 2005 and the Energy Independence and Security Act (EISA) of 2007 that set an energy standard of 36 billion gallons of renewable fuels by 2022 (U.S. Congress 2007). It is anticipated that responses to such biofuel goals will include cropping pattern changes and land conversions, even though some studies report that increased biomass production toward biofuels can have adverse environmental impacts due to land conversion (Toman, Griffin, and Lempert 2008).

The 2007 EISA capped grain-based biofuels at 16 billion gallons, with the remainder of the 20 billion gallons of ethanol to be derived from cellulosic plant material. With the burden of more than half of the renewable fuel standard being on cellulosic plant materials coupled with competition from the traditional food crops for the available land, production of biomass crops for ethanol can be expected to extend to marginal lands and lands with degraded production capabilities (Lal and Pimentel 2007).

Such expansion to produce bioenergy feedstocks by the agricultural sector has the potential to create unintended environmental consequences. For example, it has been hypothesized that biofuel initiatives can result in shifting of current cropped acres, pasture land, and conservation acres across the country toward corn and other cellulosic biofuel crops that demand increased application of chemicals and fertilizers (Simpson et al. 2008). Over time, an increase in chemical and nutrient use can cause a rise in pollutants loading to water bodies (Pimentel and Lal 2007) along with other potential impacts of reduced soil productivity (Lal and Stewart 1995).

The awareness of water pollution issues prompted the U.S. to direct greater attention toward identification and development of pollution control policies. The 1985 Farm Security Act mandated several national erosion and water pollution control programs, mainly through adoption of Best Management Practices (BMPs) specifically designed to address agricultural pollutants, such as sediments, Nitrogen (N), Phosphorus (P), and pesticides known to reach water bodies and affect water quality (Logan 1993). BMPs are management options that have been proven effective in reducing pollutant levels reaching the water bodies along with other criteria. Yuan and Binger (2002) reported that soil loss from agricultural cropland is one of the major sources of water quality deterioration and that management practices to reduce soil erosion have the potential to improve water quality.

Economic losses due to impaired water quality can take a number of forms, such as health costs, water treatment costs, lost recreation opportunities, reduced biodiversity, fish and shellfish productivity, etc. Although exact estimation of such costs is difficult

to measure, Ribaud (1992) calculates the costs of impaired water quality from U.S. cropland erosion to be in the range of \$2 to \$8 billion per year. In addition, the U.S., through the Environmental Quality Incentive Program (EQIP) shares the costs of voluntarily-implemented practices adopted by agricultural producers to protect water quality. These costs are estimated to be greater than \$500 billion since the implementation of the Clean Water Act in 1972 (Akobundu and Riggs 2000). However, such costs are not fully reflected in the prices paid either for agricultural fertilizers-and-chemicals or in cost-benefit calculations in deciding which crop to produce or how to produce, reflecting failures to internalize the externalities.

Impacts on water quality through runoff exhibits the characteristics of an externality, which Arrow (1969) defines as

“A situation in which a private economy lacks sufficient incentives to create a potential market in some good, and the nonexistence of this market results in loss of efficiency.”

BMPs can be expected to vary in effectiveness, expected usefulness over time, maintenance requirements, and establishment and operation costs, making the decision to adopt BMPs economic in nature. Agricultural producers making crop management decisions usually lack sufficient incentives to account for the damages associated with nutrient and sediment runoff or to divert time and money from other operations within the enterprise. Hence, economic incentives and other policy instruments are necessary to internalize the water pollution externality and achieve social optimality.

An earlier study (Pimentel and Lal 2007) suggested that biofuels production could have detrimental effects on water quality lacked empirical evidence to support their hypothesis. Moreover, critics suggest a need for research to identify the unintended consequences such as water quality impacts of biomass crop production. In this context, it is imperative to note that there may be unintended consequences related to the response of production agriculture to federal energy policy. It is appropriate to estimate the impacts of biofuels on water quality and the implications of policies in the form of BMPs and to mitigate these damages (negative externalities), if biofuels are to become a sustainable energy solution.

The impact of a BMP on water quality is a challenge to estimate as BMPs can differ in terms of both reduction targets achieved and costs associated with their adoption. This study helps identify the potential impacts of biofuel feedstock (cellulosic) crop production and applies a methodology useful for obtaining information to support watershed-level decision making to protect water quality as a case study.

A study by McLaughlin (2011a) evaluated the production of a cellulosic feedstock (High Energy Sorghum) sufficient to meet the feedstock need of a 30-million gallon per year ethanol conversion facility in Middle Gulf Coast, Edna-Ganado, Texas area. McLaughlin's research was directed toward providing a comprehensive analysis of the estimated costs of production associated with supplying biomass feedstock to an ethanol conversion facility. The results reported herein are an extension of the McLaughlin study relative to implications of externalities associated with biomass feedstock production and policy options to mitigate the associated negative impacts.

2.2 Objectives

Very few studies have evaluated the impact of biofuel crop production and its potential impact on water quality (Thomas et al. 2009). Management practices adopted to mitigate any such unintended consequences vary across locations in terms of their efficiency (Santhi et al. 2006). Hence, a careful assessment of the effectiveness of individual BMPs and their associated costs are valuable to evaluate the comprehensive impacts that would help decision makers, including policy makers and producers, determine the costs and benefits of BMP implementation. The specific objectives include:

1. Apply the Soil Water Assessment Tool (SWAT) to evaluate the production of a potential biomass energy crop, High Energy Sorghum (HES), over a period of 33 years, 1975-2008, in a Middle-Gulf Coast, Texas watershed and identification of the related impacts on water quality with respect to runoff and associated N, P, and soil erosion.
2. Evaluate the potential of BMPs to mitigate water quality damages (i.e., mitigate N, P, and sediment runoff) in the watershed associated with biomass crop production.
3. Conduct economic analyses based on the SWAT modeling effort to estimate the costs of BMPs implemented, both individually and in combination with other BMPs.

2.3 Study Area

The study area (figure 2-1) is the Tres-Palacios River watershed of the Middle Gulf Coast of Texas. This watershed comprises an area of 2,300 square miles (nearly 1.5 million acres) that flows into Matagorda Bay. The study area covers parts of Fayette, Colorado, Wharton, Jackson, and Lavaca counties.

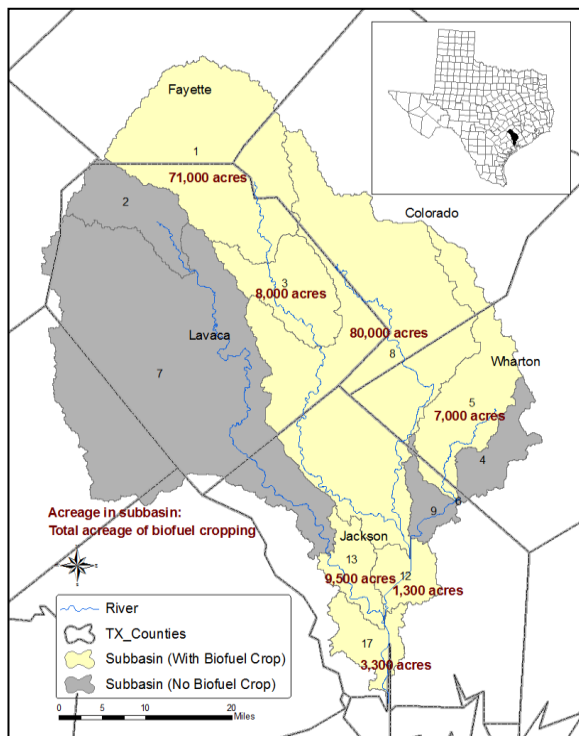


Figure 2-1. Subbasins of the Tres-Palacios river watershed, Texas where high energy sorghum is assumed to replace pasture to supply biomass for a hypothetical 30-million gallon ethanol plant

The region is characterized by an annual average precipitation of 42 inches and an average slope of the landscape of 0.8 percent. Land uses in the watershed include a mixture of rangeland, pastureland, and cropland. The watershed is divided into 17 subbasins for the purpose of this study. SWAT (Arnold et al., 1998) utilizing GIS datasets including DEM, land use, and soil generated hydrological parameters such as slope, soil and land

use parameters. Figure 2-1 is an illustration of the area of the watershed and its location in the state of Texas. Much of the region in the watershed was once planted to rice, but has reverted to pasture beginning in the 1980s. The light colored areas in the picture represent the subbasins where the HES production was assumed to replace pasture in the current analysis.

2.4 Soil Water Assessment Tool Model

Accurate representation of physical, chemical, and biological activities involved in pollution transport requires complex data sets and sophisticated hydrologic models (Powers 2007). SWAT is one such hydrological model developed by U.S. Department of Agriculture (Arnold et al. 1998) that operates on a daily time step and provides load estimates with a high level of spatial detail for a watershed, or any other study region by allowing the watershed to be divided into subbasins. Each subbasin is further divided into several land use and soil combinations, Hydrological Response Unit (HRU). Predominant soil types and land uses of the subbasins used for HES cropping in the Tres-Palacios River Watershed are summarized in table 2-1.

Application of the SWAT model provides estimates of runoff, sediment, and nutrients from the watersheds with varying soils, land use, weather conditions, and management practices. The major components of the SWAT modeling approach automatically process GIS datasets such as Digital Elevation Model (DEM), land-use, and soil to delineate and characterize watersheds and channel networks. The model also applies data on weather, crops, nutrient and pesticide applications, and management practices as inputs. A full description of all components can be found in Arnold et al.

(1998). SWAT has been extensively validated across the U.S. and internationally for stream flow, nutrients, and sediment yield (Santhi et al. 2006; Lee et al. 2011a).

Table 2-1. Land Use, Soil Types, Number Of Acres, And Slope Of Each Subbasins Of The Tres-Palacios River Watershed, Texas Where HES Production Is Assumed To Replace Pasture To Supply Biomass To A Hypothetical 30-Million Gallon Per Year Ethanol Plant

Subbasins	Original Land Use	Soil Types	Acres ^a	Slope (%) ^b
1	Pasture	Dubina and Hallettsville	71,000	3.0
3	Pasture	Tremona	8,000	2.1
5	Pasture	Bernard	7,000	0.2
8	Pasture	Dacosta, Ligon, and Telferner	80,000	0.7
12	Pasture	Texana	1,300	0.2
13	Pasture	Ligon	9,500	0.8
17	Pasture	Dacosta	3,300	0.3
Total Acres			180,100	

^a The watershed has other subbasins that are not used for HES production. The acres presented in the table represent the acreage of each subbasin that is assumed to replace pasture and produce HES. Hence, the acres are less than the 1.5 million acres that comprise the entire watershed.

^b The average slope of the subbasins presented in the table here is 1.0 percent, whereas the entire watershed, which also comprises of other subbasins (Refer to figure 2-1) has an average slope of 0.8 percent.

2.5 Best Management Practices (BMPs)

The modeling of BMPs and their effectiveness in reducing nutrient and sediment runoff have been researched and reported in many studies (e.g., Rister et al. 2009; Santhi et al. 2006), all of which have found positive effects of BMPs. For the purpose of this study, two BMPs, filter strips and cover crop, were selected. Filter strips are considered one of the more important BMPs to minimize runoff from lands with slopes of less than five percent (Grismer, O'Geen, and Lewis 2006); the average slope of the entire watershed in this study is 0.8 percent. Rister et al. (2009) demonstrated the relative

economic superiority of filter strips relative to numerous other possible BMPs to mitigate water quality damages in the Cedar Creek reservoir in Texas. Similar benefits are associated with using a cover crop, which grown after the harvest of a main crop (HES in this study) is able to capture nitrates in soil and reduce nitrate-leaching and runoff (McCracken et al. 1994). Yaun and Bingner (2002) used winter-wheat as a cover crop and evaluated the potential to mitigate sediment runoff in a Mississippi Delta watershed identifying 22 to 39 percent reductions in sediment runoff. Based on the prior research studies, filter strips and cover crops appear to be viable potential BMPs for mitigating sediment and nutrient runoff. Brief descriptions of the filter strip and the cover crop BMPs implemented in the study are provided below.

2.5.1 Filter Strips

One potential conservation practice aimed at mitigating pollutants in runoff is the development of filter strips. Filter strips are vegetative areas located within and between agricultural fields and water bodies. These BMPs are intended to intercept and reduce the velocity of flow, capture nutrients, sediments, and pesticides (Natural Resources Conservation Service 2010), potentially improving the quality of off-site surface waters and possibly groundwater.¹ As a result, nutrients and other chemicals are absorbed into the sediment and remain in the strip or are taken up by plants, which can later be removed through harvesting the vegetation. While the performance of filter strips depends on site and climatic factors, studies have shown that they have a positive

¹ The impact of energy crop production on groundwater quality is not addressed in this paper.

impact on water quality with 50 percent sediment and N-trapping (Helmets et al. 2008, Rister et al. 2009).

The unit of analysis for the filter strip in this study is assumed to be 21 acres, i.e., one acre of filter strip for 20 acres of cropland, represented as 20:1 ratio. In addition, the life of the filter strips is assumed nine years, i.e., once the filter strips are established in year one, proper maintenance would allow them to provide runoff mitigation for eight additional years prior to reestablishment being required (Rister et al. 2009).

2.5.2 Cover Crop

A cover crop BMP involves establishing native or introduced vegetation, usually sown after the harvest of the main crop, to provide a protective cover for the soil. In this study, an initial cover crop is planted during the two-year fallow period on each of the 60,000 acres used to produce HES during the previous year. At the end of the first fallow year, a second cover crop is planted on that same 60,000 acres. Following two years of fallow, HES is planted on the 60,000 acres to continue the three-year cycle. This rotation pattern is repeated throughout the modeling period of 33 years.

2.5.3 Combination Best Management Practices

Additional BMP scenarios are considered in which both a cover crop and filter strips (referred as combination BMPs in the remainder of the paper) are simultaneously implemented in the watershed. These BMPs represent a two-tier level of mitigation reducing runoff immediately within the field area by the cover crop and on the perimeter of the field by filter strips (figure 2-2).

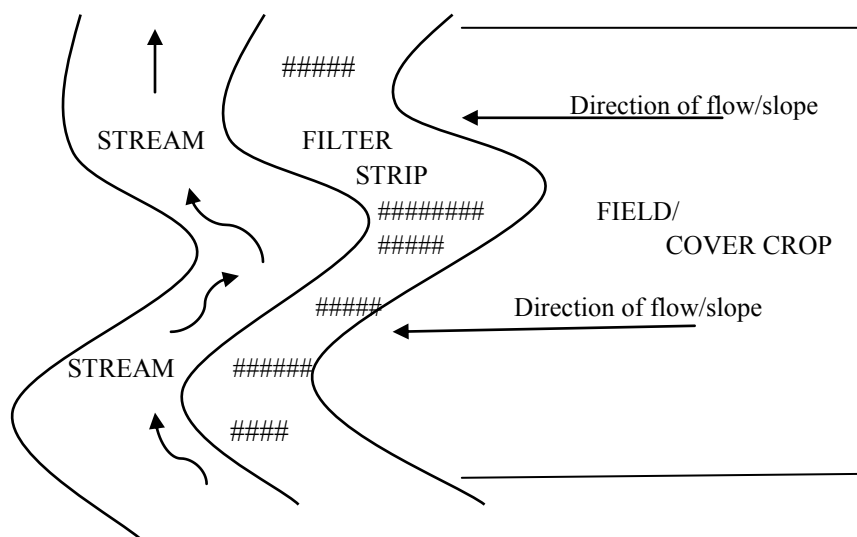


Figure 2-2. Illustration of the two-tier impact of combination best management practices, cover crop and filter strip implemented simultaneously to mitigate water quality externality

Figure 2-2 is a representation of the combination of cover crop and filter strip BMPs, where the arrows in the field area indicate the direction of the runoff. A cover crop on the field absorbs residual nutrients and minimizes soil erosion, whereas the filter strip on the perimeter of the field traps mobile nutrients and sediments at the edge of the field. The expected beneficial effects include protection of the soil from erosion until the next crop and absorption of residual nutrients from the previous crop, thus reducing soil and nutrient runoff.

2.6 Methodology

This study consists of two procedural components: (1) the methodology associated with the implementation of the cropping scenarios with and without BMPs and identification of the potential impacts on nutrient and sediment runoff applying SWAT; and (2) the methodology associated with identification of economic costs of

BMPs and estimation of Net Present Value (NPV) and Annuity Equivalent Value (AEV) of all costs.²

SWAT analyses in this study utilize past and current flow data to estimate the implications on water and land resources, first with the current cropping pattern (pasture) and then as a result of producing HES, with and without BMPs, in the Tres-Palacios River watershed. HES, being a non-food crop is widely under consideration as a potential cellulosic biofuel crop (Fulton, Howes, and Hardy 2004), and is hypothetically used as a replacement to the current land use (i.e., pasture) in the analyses.

Flow calibration was performed for annual and monthly simulated flows using observed flows from U.S. Geological Survey gauge stations at Hallettsville, TX (08164300) and Speaks, TX (08164350) for the periods of 1975-2008. The calibration process ensures that the simulated flows match the observed flow at the gauge stations. Continuous records of the monitoring data for sediments and nutrients were not available for calibration for the Tres-Palacios River watershed. Hence, rigorous calibration of runoff of nutrients and sediments was not performed, which implies that the results are to be interpreted in a relative sense, rather than absolute values. Detail flow calibration processes can be found in Lee et al. (2011a).

2.6.1 Cropping Scenarios

The three priority cropping scenarios in the study include pre-HES, HES with no BMPs, and HES with selected BMPs. The pre-HES scenario reflects the baseline scenario (i.e., existing pasture conditions), whereas the HES with and without BMPs

² NPV and AEV are subsequently discussed in the financial analyses section of the methodology.

reflect the biofuel crop scenarios where the existing pasture is replaced with HES crop production.

2.6.1.1 Pre-High Energy Sorghum Scenario

In the pre-HES setup, the water quality information is estimated under the existing pasture conditions and nutrient application rates, which are 50 lb of N and 11 lb of P per acre (Falconer 2010). The management operations and the associated time-periods for the pre-HES scenario (baseline) are presented in table 2-2.

2.6.1.2 High Energy Sorghum With No Best Management Practices Scenario

The biofuel crop scenario focuses on growing HES on what is currently pasture land. The scenario is implemented in a three-year rotation (one year of HES production and two years of fallow), for a modeling period of 33 years, 1975-2008, including two model warming-up years. Following McLaughlin (2011a), the HES production is in randomly-selected pasture fields in different subbasins across the watershed and based on a 3-year rotation (table 2-2), one year of HES and two years of fallow, over 60,000 acres each year, totaling 180,000 acres of HES cropland over a three-year period. The resulting changes in water quality for post-HES production are compared against the pre-HES to estimate the changes in nutrient and sediment runoff from each subbasin and the entire watershed.

Table 2-2. Management Operations And Corresponding Time Periods For The Pre-HES (Baseline) Scenario And Post-HES (Biofuel) Scenario^a Implemented At Tres-Palacios River Watershed To Estimate Changes In Nutrients And Sediment Runoff

Scenario	Date ^b	Year ^c	Operation	Note
Baseline	4/1	1	Pasture	
	4/15	1	Fertilizer	50 lb N/acre, 11 lb P/acre
	7/1, 9/1, 11/1	1	Harvest	
<hr/>				
Biofuel	10/1, 10/15, 11/1	1	Tillage	
	12/1	1	Fertilizer ^d	240 lb N/acre, 80 lb P/acre
	4/1	2	Plant HES	
	4/15, 5/1	2	Irrigation	8.3 inches per irrigation
	9/1	2	Harvest	Yield: 10-12 wet tons per acre
	10/1	2	Voluntary Vegetation	
	9/1	3	Voluntary Vegetation	

^a The biofuel crop operation schedule in this table is an example of 2nd year cropping.

^b Indicates date of corresponding operation, for example, 4/15 in baseline indicates fertilizer was applied on April 15.

^c Indicates a pre biofuel and a three-year rotation of biofuel crop, 2 indicates that the biofuel crop is taken up in the second year, whereas 1 and 3 indicate native grass is allowed to grow in years one and three during the three-year rotation period.

^d SWAT does not simulate K; hence, K applications are not reported.

To simulate nutrients and sediment outflows, fertilizer application rates for both pasture and HES were obtained from personal communications with Dr. Larry Falconer (2010), a Texas AgriLife Extension economist, and Dr. Juerg Blumenthal (2011), a former extension agronomist with Texas AgriLife Extension. Information regarding other management decisions such as planting, field operations, and harvesting dates were obtained from personal communications with Mr. Will McLaughlin, a former graduate student in Department of Agricultural Economics, Texas A&M University

(McLaughlin 2011b).³ Model runs of SWAT were conducted to estimate the changes in nutrient and sediment loadings from the watershed. Table 2-2 is a summary of the scenarios, management operations, and corresponding time-periods associated with the three-year rotation of HES production.

2.6.1.3 High Energy Sorghum With Best Management Practices Scenario

SWAT analyses provide opportunities to evaluate the long-term effects of the BMPs related to the mitigation of soil and nutrient losses. The agricultural management options considered primarily focus on adoption of feasible BMPs such as filter strips, riparian buffers, cover crop, grassed waterways, etc. (Rister et al. 2009). The changes in nutrient and sediment runoff are estimated due to implementation of the BMPs with HES production. Model-run results for HES with and without the BMPs scenarios are compared to estimate the effect of the BMPs in mitigating the sediment and nutrient loadings. With an objective to mitigate the increased offsite load in sediment and nutrient runoff occurring because of HES production, the results are reported as percentage reductions achieved due to adoption of the BMPs. Such a modeling approach is useful in addressing the water pollution issues and in providing relevant information to the policy designers and decision makers (i.e., agricultural producers).

2.6.2 Economic And Financial Analyses Of Best Management Practices

Following estimation of the mitigation levels achieved using the respective BMPs being considered, economic and financial information is identified, organized,

³ Mr. Will McLaughlin obtained this information through personal communications with agricultural producers in the Middle Gulf Coast, Texas (McLaughlin 2011a). This information was later shared with the authors of this paper.

and evaluated to facilitate recognition of the most cost-efficient solutions for mitigating the water quality externalities. In addition to the technical performance levels of the BMPs presented in the previous section, the information required to identify all relevant costs of individual BMPs include:

- Mitigation level achieved by each BMP;
- Number of acres affected by the BMP;
- Expected life (i.e., years of productive reduction in Total Phosphorous (TP), Total Nitrogen (TN), and Sediments) for the BMP;
- Initial investment, i.e., construction and implementation costs;
- Annual operating and maintenance costs;
- Revenues associated with the BMP, e.g., grazing income;
- Level of current adoption and maximum adoption allowed; and
- Appropriate discount rate that accounts for inflation, risk, and time value.

Moreover, to estimate the costs of BMPs adoption, identification of specific management practices and their associated costs are essential. A brief description of the management operations and the associated costs and revenues of the individual BMPs considered for the study are presented below.

2.6.2.1 Filter Strips Management

Annual ryegrass serves for the establishment of filter strips in the current analysis. Patty, Real, and Gril (1997) conducted a study using ryegrass for filter strip establishment and found that nitrates, phosphates, and suspended solids were all reduced

by approximately 100 percent. The list of management operations, time-periods of operations, and associated costs per acre for the establishment of the filter strips BMP are presented in table 2-3.

Table 2-3. Management Operations, Time Period Of Operations, And Associated Costs Per Acre For The Establishment Of Filter Strips, Tres-Palacios River Watershed, Texas

Month	Operations Yr-1	Operations Yrs 2-9 ^a	Costs, Yr-1 (\$/acre/yr)	Costs, Yr-2-9 (\$/acre/yr)
	Rent Land: 3,000 acres	Rent Land: 3,000 acres	\$ 15.00	\$ 15.00
Late Fall	Aerial broadcasting of Ryegrass seed @ 30 lbs/ac		35.80 ^b	-
Late Fall	-	Aerial broadcasting of Ryegrass seed @ 20 lbs/ac		17.20 ^b
	Grazing ^c	Grazing	0.00	0.00
	Aerial application of Broad Leaf Herbicide	Aerial application of Broad Leaf Herbicide	11.00 ^d	11.00
	Management	Management	3.00	3.00
	Total Costs		\$ 64.80	\$ 56.20

^a Management operations for years two through nine, as filter strips are assumed to have a useful life of nine years.

^b Seed costs at \$43 for a 50 lbs bag of Ryegrass (Seedland 2012) and aerial flying costs at \$10/acre (Texas AgriLife Extension Service 2011).

^c Grazing is not allowed throughout the project period to maintain crop stand and facilitate runoff minimization.

^d Herbicide cost at \$6/acre and aerial flying costs at \$5/acre (Texas AgriLife Extension Service 2011).

Additional land is assumed rented for the establishment of the filter strips, as the biomass acreage is required to be maintained at 60,000 acres to supply sufficient biomass to facilitate production at a 30-million gallon per year ethanol conversion facility (McLaughlin 2011a). The intensity of the filter strip design is used to estimate the amount of additional land required, i.e., for 20:1 filter strips, 3,000 acres of additional land are required (i.e., 60,000 acres divided by 20). In addition, a nine-year useful life is assumed for the filter strips, and at the end of ninth year, the filter strips are

terminated and the nine-year management sequence is repeated (Rister et al. 2009) for the modeling period of the project. A similar approach is followed to estimate the additional land requirement for filter strips of different intensities. The total costs presented in table 2-3 indicate that filter strips cost \$64.80 per acre for year one and \$56.20 per acre per year during years two through nine, applicable to 3,000 acres of filter strips at the 20:1 ratio of cropped land to filter strip.

2.6.2.2 Cover Crop Management

Annual ryegrass also serves as the cover crop BMP. Ryegrass has been evaluated in several studies to estimate impact on nutrients in runoff, mainly nitrogen. Martinez and Guiraud (1990) used ryegrass as a cover crop in a wheat-corn rotation and found a reduction in nitrate leaching of 67 percent, suggesting that ryegrass takes up the nutrients during its growing period and will be effective in reducing nutrients in runoff from the field.

Ryegrass is used as the cover crop in the current analysis on all 60,000 acres during each of the two years following HES production. At the end of the second year, HES crop production replaces the cover crop on the 60,000 acres. This production cycle/sequence is repeated throughout the modeling period. The list of management operations, time-periods of operations, and associated costs per acre for the establishment of the cover crop BMP are presented in table 2-4.

Table 2-4. Management Operations, Time Period Of Operations, And Associated Costs Per Acre For The Establishment Of A Ryegrass Cover Crop, Tres-Palacios River Watershed, Texas

Month	OperationsYr-2	Operations Yr-3	Costs, Yr-1, (\$/acre/yr)	Costs, Yr-2, (\$/acre/yr)
Sept/Oct	Tandem Disk	-	\$ 17.10	\$ 0.00
	Field Cultivation	-	12.60	0.00
	Min-till Drill Ryegrass @ 30 lbs/acre ^a	Min-till Drill Ryegrass @ 30 lbs/acre	42.70	42.70
	Reseed 25% acreage by aerial broadcast @ 30 lbs/acre ^b	Reseed 25% acreage by aerial broadcast @ 30 lbs/acre	8.90 ^c	8.90 ^c
	Fertilizer ^d	Fertilizer	0.00	0.00
Dec-Mar	Grazing	Grazing	(5.00) ^e	(5.00) ^e
Apr/May	Min-till Drill Sudangrass @12 lbs/acre ^f	Min-till Drill Sudangrass @12 lbs/acre	34.90	34.90
	Reseed 25% acreage by aerial broadcast @ 12 lbs/acre	Reseed 25% acreage by aerial broadcast @ 12 lbs/acre	5.30	5.30
June/Aug	Grazing	Grazing	(5.00) ^e	(5.00) ^e
Sept	Transition to Second year of cover crop rotation	Transition to HES production		
	Management Costs	Management Costs	10.00	10.00
Total Costs			\$ 121.40	\$ 91.70

^a The min-till drill at 30 lbs/acre in Sept/Oct improves germination and allows for early spring grazing. The costs include drilling rate per acre (Texas AgriLife Extension Service 2011) and Ryegrass seed costs. The Cost of 30 lbs/acre at \$43 for a 50 lbs bag of Ryegrass (Seedland 2012).

^b Reseeding is done to compensate low seed establishment.

^c Cost of 30 lbs/acre on 25% acreage at \$43 for a 50 lbs bag of Ryegrass (Seedland 2012) plus \$10/acre aerial flying costs during reseeding (Texas AgriLife Extension Service 2011).

^d No fertilizers are applied assuming residual fertilizers from HES production will supply the necessary nutrient requirement.

^e Values in the parentheses indicate revenues.

^f Ryegrass becomes a possibility to plant as a cover crop beginning in August. Thus, after spring grazing, Sudangrass is min-till drilled to maintain a vegetative cover on the field. The costs include drilling rate per acre (Texas AgriLife Extension Service 2011) and Sudan grass seed costs. The Cost of 12 lbs/acre at \$1.50/lb of Sudan grass (Stock Seed Farms 2012).

2.6.2.3 Financial Analyses Of Best Management Practices

To compare the potential BMPs, common units of expression are needed (i.e., NPV and AEV), recognizing establishment costs, operating costs, expected useful life,

and associated runoff reduction performance. NPV estimates represent the present value of funds needed to implement and maintain the BMPs for the entire life of the project, whereas the AEV of the costs correspond to calculated annual payments during the project period necessary to pay for the establishment and operation of the BMPs (Rister et al. 2009). In other words, AEV represents the annual payment in each of the 33 years of the project period that is necessary to finance the implementation of the BMP practice/project. Moreover, AEV, unlike NPV, takes into account the life of the BMPs and allows relative comparisons across BMPs.

Once the requisite information is secured and validated, a modified version of BMPEconomics, a Microsoft Excel spread sheet (Rister et al. 2009), is applied to calculate the NPV of all costs and returns over the expected life of the BMPs. Subsequently, the NPV is transformed into an AEV, assuming 100 percent implementation within the SWAT-designated subbasins of the Tres-Palacios River watershed. It is also important to identify whether implementation of an individual BMP or a combination of BMPs provides the most effective benefit (reduction of contaminants compared to costs). Hence, the NPV and AEV of the costs for the combination BMPs are also estimated⁴.

In addition, the aggregate costs of nutrient and sediment reduction information are transformed to identify annual costs per unit reduction. In estimating these costs per unit of reduction, Total Phosphorous (TP), Total Nitrogen (TN), and sediment are evaluated independently, assuming all costs are associated with reducing that particular

⁴ Recall that the combination BMPs are cover crop and filter strips that are simultaneously implemented.

pollutant and ignoring any costs toward reducing the others. For each BMP, a 100 percent adoption rate is assumed along with an annual inflation rate of 1.9 percent and a time preference rate of 4.1 percent (Office of Management and Budget, 2011), resulting in an aggregate discount rate of 6.0 percent, which facilitates in calculations of NPV and AEV.

2.7 Results

The results are divided into SWAT estimates for the alternative scenarios described above. The physical mitigation impacts on water quality are first identified, followed by presentation of the economic implications of implementing BMPs.

2.7.1 Results Of The Soil Water Assessment Tool Analyses

The introduction of agriculturally-intensive bioenergy crops is expected to result in an increase in pollutant loading to downstream water bodies. In this study, the expected average increase in annual loadings of TP, TN, and sediments occurring because of biomass crop production are estimated for the Tres-Palacios River watershed, Texas through the application of the SWAT model.

2.7.1.1 Pre-High Energy Sorghum

Pre-HES loadings (i.e., loadings under existing pasture conditions) of TP, TN, and sediments at each of the subbasin outlets, all measured in English Tons (ET)⁵, are presented in table 2-5.

⁵ One English ton = 2,000 lbs

Table 2-5. Average Of Nutrient And Sediment Runoff At Each Subbasin Outlet Associated With Pre-HES Scenario, Tres-Palacios River Watershed, Texas

Subbasin ^a	TP	TN	Sediment
	-----English Tons ^b -----		
1	16	134	8,117
3	25	228	19,315
5	163	891	81,165
8	188	968	64,138
12	421	1,846	119,149
13	66	354	21,546
17 ^c	497	2,027	59,701

^a Refer to figure 2-1 to identify the subbasins in the watershed.

^b One English ton = 2,000 lbs.

^c Watershed Outlet.

The outlet of the entire watershed is located in subbasin 17, where the estimated losses represent the cumulative effect of the cropping patterns, both upstream and within the subbasin. At the watershed outlet (i.e., subbasin 17), annual runoffs of TP, TN, and sediments are 497 ET, 2,027 ET, and 59,701 ET, respectively. These runoff estimates form the status-quo levels. Any changes in runoff because of HES production and implementation of BMPs are measured relative to these levels.

2.7.1.2 High Energy Sorghum With No Best Management Practices

Driven by the economics of input costs, ethanol prices supplemented by the biofuel subsidies, and no regulation to control non-point source pollution, the current goals related to U.S. energy production would likely result in the trend of expansion of biomass feedstock production. Nutrient and sediment runoffs occurring because of conversion of pasture to HES production, measured as average annual runoffs at each of

the subbasin outlets, and the percentage change in runoff from the baseline are presented in table 2-6.

Table 2-6. Average Nutrient And Sediment Runoff At Each Subbasin Outlet And Absolute Percent Change From The Baseline Associated With Pre-HES Production, Tres-Palacios River Watershed, Texas

Subbasin ^a	TP			TN			Sediment		
	Post-HES	Change from Baseline	Percent Change	Post-HES	Change from Baseline	Percent Change	Post-HES	Change from Baseline	Percent Change
	English Tons ^a			English Tons ^a			English Tons ^a		
1	147	131	819%	694	560	418%	251,397	243,280	2997%
3	153	128	512%	748	520	228%	146,103	126,788	656%
5	180	17	10%	972	81	9%	88,319	7,154	9%
8	383	195	104%	1,495	527	54%	88,533	24,395	38%
12	629	208	49%	2,332	486	26%	143,628	24,479	21%
13	76	10	15%	371	17	5%	22,838	1,292	6%
17 ^c	714	217	44%	2,438	411	20%	68,463	8,762	15%

^a Refer to figure 2-1 to identify details on the subbasins in the watershed.

^b One English ton = 2,000 lbs.

^c Watershed Outlet.

The results in table 2-6 indicate that the annual runoff of TP, TN, and sediments at the watershed outlet (subbasin 17) are 714 ET, 2,438 ET, and 68,463 ET, respectively. As a result, the changes in loadings compared to the baseline indicate an increase by 217 ET, 411 ET, and 8,762 ET for TP, TN, and sediment, respectively. The magnitude of increased runoff is largely due to nutrient application levels to the cropland followed by heavy rainfall events that occur in the watershed region.⁶ Several research investigations have proven that fertilizers on cropland are transported over the land into tributaries

⁶ Refer to McLaughlin (2011a) to identify the average and range of Wharton County monthly rainfall for years 1984-2009. Wharton County harbors the Tres-Palacios River watershed.

during heavy rainfall events (Gascho et al. 1998). The region has experienced high rainfall events over the past 25 years, mostly during the months of October and November, which coincides with either the harvest period of the HES crop or the post-harvest fallow period.⁷ The absence of vegetative cover coupled with high rainfall events is expected to be a major contributing factor to increased runoff from the watershed.

Although the rotation pattern of one year of HES followed by two years of fallow is used to minimize nutrient depletion, harvesting maximum biomass from an acre of land results in depletion of the organic matter and, thus requires greater levels of fertilizer nutrients in the following growing seasons (McLaughlin 2011b). Such fertilizer applications followed by heavy rainfall events precipitate increased runoff from the fields, evident from the results presented in table 2-6.

The estimates derived in this study suggest that conversion of 180,000 acres from pasture to a three-year rotation of HES-fallow-fallow results in increased soil and nutrient runoff compare to the pre-HES loadings (table 2-6). Estimation of percentage changes in nutrient and sediment runoff compared to the pre-HES scenario can be useful in identification of the most susceptible subbasins. These percentage changes will allow targeting the development of a watershed protection plan that focuses on relative improvement of the most vulnerable subbasins of the watershed. Hence, percentage changes in runoff because of HES production compared to the pre-HES runoff are

⁷ Refer to table 2-2 to identify the dates of management operations of the biofuel crop.

reported in table 2-6 and presented in figure 2-3, where panels a, b, and c represent the average annual percentage change in TP, TN, and sediments, respectively.

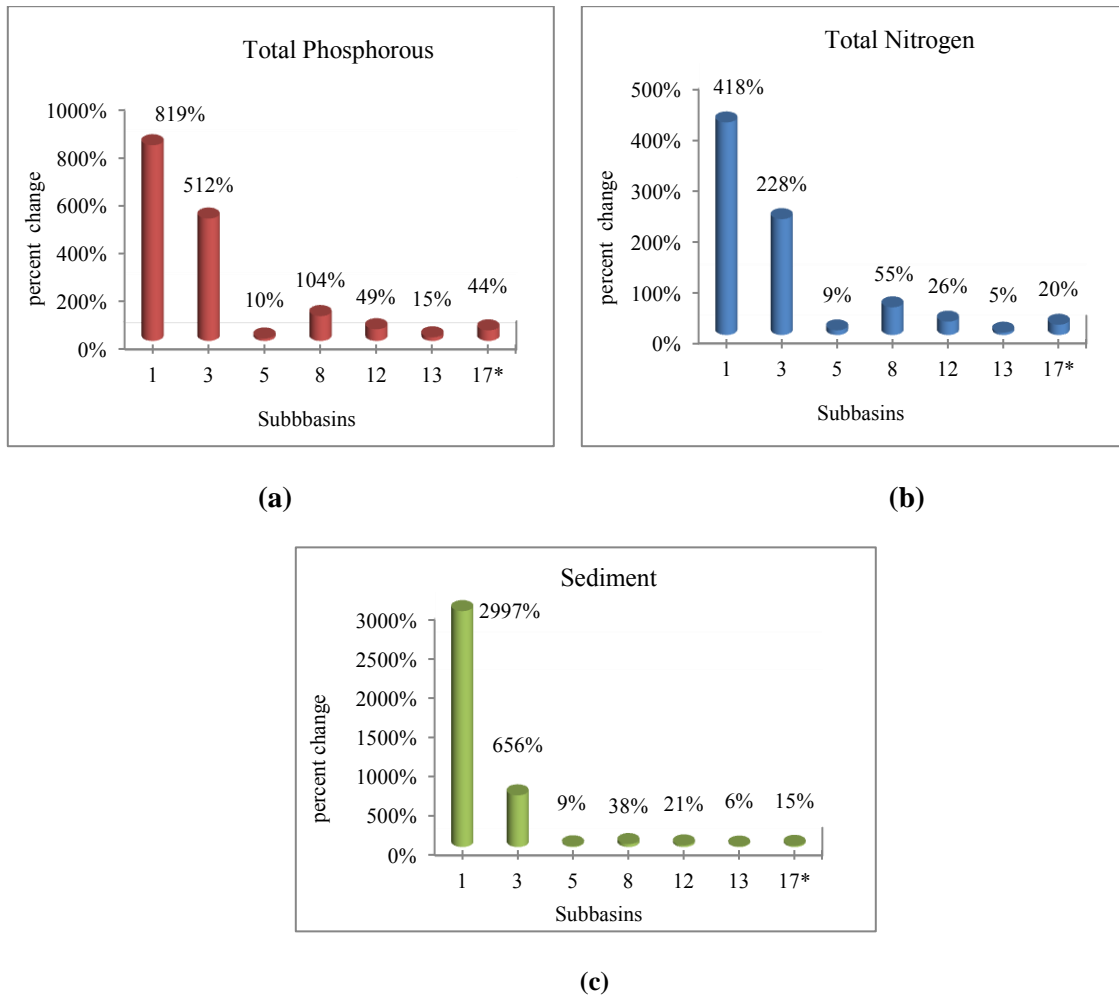


Figure 2-3. Average annual percentage increase in total phosphorous, total nitrogen, and sediments compared to the baseline conditions (i.e., pre-high energy sorghum loadings) at each subbasin outlet because of high energy sorghum crop production during the years 1975-2008, Tres-Palacios river watershed, Texas

Note: * = watershed outlet

Estimation of percentage changes indicates that subbasins 1 and 3 are the most vulnerable with respect to expected increase in nutrient and sediment runoff compared to pre-HES runoff estimates. Higher annual losses from subbasins 1 and 3 are mostly

attributed to the greater slopes associated with these two subbasins.⁸ TP runoff from subbasins 1 and 3 increased by 819 and 512 percent, respectively, compared to the Pre-HES loadings. TN and sediment reflect a similar trend as TP, with the highest percentage increases in runoff occurring again in subbasins 1 and 3. Sediments in runoff increased by 3,000 percent in subbasin 1, primarily attributed to the expansion of production to fragile lands, i.e., the lands with an erosion index of 8.0 or higher (Farm Service Agency 2012).

It is assumed that fertilizer nutrients are applied to realize a yield of 12 dry tons per acre⁹. However, existing field conditions that are not known with certainty during the growing season of the crop could influence the fertilizer application levels (McLaughlin 2011b). Such production decisions coupled with uncertain rainfall events can result in increased loadings to the off-site surface waters. In addition, HES production for this analysis was based on requiring two irrigations of 8.3 ac-in per irrigation (McLaughlin 2011a) compared to no irrigation for pasture, partly influencing the runoff loadings.

The runoff estimates measured at the watershed outlet (subbasin 17) that opens up into the bay indicate that TP, TN, and sediments increased by 43, 20, and 15 percent, respectively, because of HES production. If the push for biomass-based ethanol continues, these results are suggestive that projected nutrient runoff and resulting offsite

⁸ Refer to table 2-1 to identify the slopes associated with each subbasin. Subbasins 1 and 3 have relatively higher slopes compared to other subbasins, i.e., 3.0 and 2.1 percent, respectively. The average slope of the entire watershed is 0.8 percent.

⁹ Although 12.0 dry tons per acre yield is considered possible for HES, only an average of 8.5 dry tons per acre are realized due to varied planting and harvesting dates to minimize costs of production (\$/dry ton) (McLaughlin 2011a).

water quality deterioration could be increased from such intensively-managed agricultural systems.

2.7.1.3 High Energy Sorghum With Best Management Practices

From a water quality perspective (i.e., to mitigate negative externalities associated with biomass production), an option is to evaluate policies that will facilitate reducing nutrient and sediment loadings to water. Research has shown that potential nutrient losses from agricultural systems could be mitigated with BMPs (Secchi et al. 2007). The two BMPs considered in this study, filter strips and cover crop, are implemented independently and in combination in the application of the SWAT model in varying degrees of intensity to estimate the resulting changes in nutrient and sediment runoff (table 2-7).

The potential mitigation achieved in runoff by each BMP is influenced by the current level of adoption of each BMP along with its marginal additional adoption rate (Rister et al. 2009). Due to lack of data, a zero level of current implementation of the BMPs is assumed along with 100 percent marginal adoption rate. The associated average annual reductions associated with the BMPs for TP, TN, and sediment are measured at the watershed outlet (subbasin 17).

Filter Strips (FS) are modeled as edge-of-field vegetation to trap the runoff from the subbasins. The FS option, with one acre of FS for every 20 acres of cropland, is associated with mitigation at the watershed outlet (subbasin 17) of 69.3 percent, 70.8 percent, and 73.5 percent for TP, TN, and sediments, respectively. TP reduction of 69.3

percent produced by the FS (20:1) BMP indicates that 30 percent mitigation is still required to achieve the pre-HES runoff levels.

Table 2-7. Desired Mitigation Levels And Effectiveness Of Individual And Combination Best Management Practices Measured At The Watershed Outlet (Subbasin 17), Tres-Palacios River Watershed, Texas

BMPs	Desired Mitigation Levels ^a		
	TP (ET ^b)	TN (ET)	Sediment (ET)
	216	410	8,762
	Mitigation (% of Desired) Achieved Through BMP Adoption		
	TP	TN	Sediment
FS (20:1) ^c	69.3%	70.8%	73.5%
Cover Crop	48.3%	55.7%	66.7%
FS (15:1) ^c	71.5%	73.7%	77.1%
FS (10:1) ^c	74.1%	77.1%	81.9%
FS (5:1) ^c	77.3%	81.7%	87.4%
CC ^d + FS (20:1) ^c	88.2%	97.0%	102.6%
CC ^d + FS (15:1) ^c	89.3%	98.4%	104.1%
CC ^d + FS (10:1) ^c	90.4%	100.1%	106.1%
CC ^d + FS (5:1) ^c	91.7%	102.0%	108.3%

^a The “Desired Mitigation Levels” are the difference in runoff loadings between the pre-HES (pasture) levels and the post-biofuel levels (table 2-6). These desired levels indicate the amount of reductions

in runoff that need to be achieved to attain pre-HES runoff loadings.

^b ET: English Ton; One English ton = 2,000lbs..

^c FS refers to filter strip BMP and (20:1) refers to the ratio of crop acres to filter strip acres.

^d CC refers to cover crop BMP acres and is assumed to be planted on all land in the rotation that is not planted to HES.

The filter strips of higher intensity are implemented to achieve improved mitigation levels so as to achieve pre-HES runoff levels. The filter strips of high intensity produced slight increase in nutrient and sediment mitigation. For example, FS (5:1), the highest level of filter strip intensity (i.e., one acre of filter strip for every five

acres of cropland) produced 77.3, 81.7, and 87.4 percent mitigation in TP, TN, and sediment, respectively. These results indicate that Pre-HES levels were not achieved and warrant additional evaluation of BMPs.

The cover crop as a single BMP was least effective in mitigating runoff of P, N and sediment. However, in combination with a filter strip, a cover crop increased effectiveness in controlling of TP, TN, and sediments (e.g., 88.2, 97.0, and 102.6 percent reduction produced by CC+FS (20:1) compared against 48.3, 55.7, and 66.7 percent reduction produced by cover crop only).

The largest nutrient and sediment reductions as a percentage of the desired mitigation were gained by the combination of cover crop and filter strip, represented as CC+FS (5:1) BMP, with 91.7 percent for TP, 102 percent for TN, and 108.3 percent for sediments. Mitigation levels exceeding 100 percent indicate that the reduction in runoff achieved the mitigation to a level of pre-HES plus some additional mitigation in excess of 100 percent. For example, TN mitigation of 102 percent produced by CC+FS (5:1) indicates that the mitigation produced exceeds the desired mitigation by 2.0 percent. Desired mitigation in runoff was achieved for TN and sediment, but not for TP.

Reductions in nutrient and sediment runoff achieved by filter strip and cover crop BMPs occur mainly through adsorption (Webster and Shaw 1996) and uptake by the vegetation. Moreover, the history of fertilizer applications to land can influence nutrient buildup and consequently loading in runoff. Since cover crop and filter strip BMPs involve production of vegetative crops, it is expected that a portion of the excess

nutrients in the soil are utilized during the growing period¹⁰, thus producing a reduction in nutrient and sediment runoff along with the reduction associated with “trapping” of the sediment and nutrients in the BMP vegetation.

It is evident from the values reported in table 2-7 that 100 percent mitigation is not achievable using solely any of the individual BMPs, but it is achievable with combination BMPs for TN and sediments. However, the maximum expected mitigation achievement for TP is only 91.7 percent. Comparison of effectiveness produced by filter strips and a cover crop indicate that filter strips produced higher mitigation levels, which is primarily attributed to the strategic placement of filter strips between a field and a water body (Lee, Narasimhan, and Srinivasan 2011b).

2.7.2 Economic Results

The economic analyses aspect of this research are focused on comparing BMP costs relative to the level of mitigation accomplished for the entire watershed, as measured at subbasin 17 rather than for each subbasin. The SWAT effectiveness levels for TP, TN, and sediment for each BMP were incorporated into the modified BMPEconomics spreadsheet to estimate the economic costs of implementing alternative BMPs. The cost information for each BMP includes initial investment, expected useful life of the BMP, and management costs. Each BMP was assessed according to its AEV of cost per ton of TP, TN, and sediment mitigation.

¹⁰ The plant growth model in the SWAT accounts for the residual nutrients present in the soil (Santhi et al. 2006).

2.7.2.1 Cost Relative To Nutrients And Sediments

Table 2-8 is a summary of the estimated AEV of all costs for each BMP, and the AEV of costs per ton of reduction of each pollutant. The percentages of desired mitigation achieved (table 2-7) through BMPs implementation are utilized to estimate the cost per ton of TP, TN, and sediment reduction. In estimating these costs, each pollutant is evaluated independently, ignoring any costs toward mitigating the other pollutants.

The AEV of all costs correspond to the annual payments necessary to pay for the initial establishment and ongoing operation and maintenance costs associated with each BMP throughout the project period of 33 years. The AEV of all costs for a filter strip system of intensity 20:1(hereafter referred as FS (20:1)) for the total 180,000 acres is \$563,862, whereas for the cover crop BMP, it is an estimated \$13,185,077. The relatively higher AEV for the cover crop BMP is primarily due to the cost associated with implementing a cover crop BMP on 120,000 acres each year compared to only 9,000 acres for the FS (20:1).¹¹

The AEV of a ton of reduction in TP, TN, and sediments are lowest for the FS (20:1) at \$3,763, \$1,942, and \$83, respectively (table 2-8). The AEV per ton of reduction in TP, TN, and sediments are highest for the cover crop BMP, however, and are \$126,188, \$57,728, and \$2,255, respectively.

¹¹ The land requirements for the implementation of the BMPs are explained in the Methodology section.

Table 2-8. Summary Of Financial Annuity Equivalent Value Of Costs Per Unit For Total Phosphorus, Total Nitrogen, And Sediments Associated With Each Of The Best Management Practices, Desired Mitigation Levels, And Effectiveness Of Individual And Combination Best Management Practices Measured At The Watershed Outlet (Subbasin 17), Tres-Palacios River Watershed, Texas

		Desired Mitigation Levels ^a					
		TP (ET ^b)	TN (ET)	Sediment (ET)			
		216	410	8,762			
BMP Description	Annuity Equivalent Value of all Costs (\$/year)	Mitigation (% of Desired) Achieved Through BMP Adoption			Annuity Equivalent Cost per English Ton of Reduction (\$/Ton/year) ^c		
		TP	TN	Sediment	TP	TN	Sediment
FS (20:1) ^d	\$ 563,862	69.3%	70.8%	73.5%	\$ 3,763	\$ 1,942	\$ 83
FS(15:1) ^d	751,816	71.5%	73.7%	77.1%	4,863	2,487	111
FS(10:1) ^d	1,127,723	74.1%	77.1%	81.9%	7,040	3,563	157
FS(5:1) ^d	2,255,447	77.3%	81.7%	87.4%	13,493	6,732	295
Cover Crop (CC) ^e	13,185,077	48.3%	55.7%	66.7%	126,188	57,728	2,255
CC ^e + FS(20:1) ^d	13,748,938	88.2%	97.0%	102.6%	72,059	34,554	1,529
CC ^e + FS(15:1) ^d	13,939,893	89.3%	98.4%	104.1%	72,196	34,530	1,528
CC ^e + FS(10:1) ^d	14,312,800	90.4%	100.1%	106.1%	73,166	34,867	1,539
CC ^e + FS(5:1) ^d	15,440,524	91.7%	102.0%	108.3%	77,853	36,895	1,627

^a The “Desired Mitigation Levels” are the difference in runoff loadings between the pre-HES (pasture) levels and the post-biofuel levels (table 2-6). These desired levels indicate the amount of reduction in runoff that needs to be achieved to attain pre-HES runoff loadings.

^b English Ton; One English Ton = 2,000 lbs.

^c Estimated as AEV of all costs divided by the product of marginal reduction achieved and desired mitigation levels; for TP and FS (20:1): 563,862/ (69.3*216) = \$3,763 per ET..

^d FS refers to filter strip BMP and (20:1) refers to the ratio of crop acres to filter strip acres.

^e CC refers to cover crop BMP acres and is assumed to be planted on all land in the rotation that is not planted to HES.

When the intensity of filter strips increase from 20:1 to 5:1, the AEV of costs increased by approximately threefold. This increase is primarily attributed to the investment and maintenance and operation costs associated with 36,000 acres of additional land under FS (5:1). The combination BMPs are significantly more expensive in total, with their AEV of costs being in the range of \$13.7 to \$15.4 million, primarily due to the presence of the cover crop BMP, which has relatively higher establishment, operation, and maintenance costs.

The high AEV of cost per ton reduction associated with a cover crop is due to high establishment, operation and maintenance costs, and a low associated marginal reduction (table 2-8).¹² It is also evident from the AEVs per ton of reduction estimates presented in table 2-8 that filter strips are the most cost-efficient, followed by a combination BMPs, and finally the cover crop BMP alone. The results also indicate a pattern where sediments are the least expensive to control, followed by TN, and then TP. The presence of cover crop in the combination BMP, however, results in relatively high AEV of costs per ton of nutrient and sediment reduction relative to the mitigation costs reflected in the filter strip BMPs alone.

The objective of this study is to estimate the AEV of costs of BMPs adopted to mitigate the water quality externality. Although an extreme case of mitigation was evaluated in the current analysis, often, social priorities determine the levels of mitigation, which can often be expected to be lower than 100 percent (e.g., Rister et al. 2009). However, it has to be noted that 100 percent reduction in runoff is not achieved

¹² Marginal reductions associated with BMPs are presented in table 2-7.

in TP, i.e., TP was not completely mitigated, whereas, 100 percent mitigation was achieved in TN and sediments at substantially higher costs. The current analysis thus identifies the process of mitigation of an externality and the associated costs of mitigation, and leaves the choice to decision makers (policy designers and agricultural producers) to determine the desired level of mitigation depending on individual and social limitations/challenges.

Although the full scope of this research encompasses attention to TP, TN, and sediments, the economic analyses of identifying the most cost-efficient means of reducing TP are elaborated below. Figure 2-4 is an illustration of the effectiveness of each BMP in mitigating TP and the associated AEV of costs per ton of reduction. The data points on the graph represent the performance level and per unit TP mitigation costs for implementing the respective BMPs in the watershed.

The cover crop BMP data point indicates that a cover crop achieves approximately 48.3 percent reduction in TP runoff at an annual cost of \$126,188 per ton. FS (20:1) achieves relatively higher reductions in TP (69.3 percent) at significantly lower per unit costs of \$3,763, indicating that FS are relatively more cost-efficient in mitigating TP runoff. Since 100 percent reduction was not accomplished with either cover crop or FS (20:1) alone, additional potential BMPs, such as only higher intensity filter strips and varying intensities of filter strips in combination with a cover crop were evaluated.

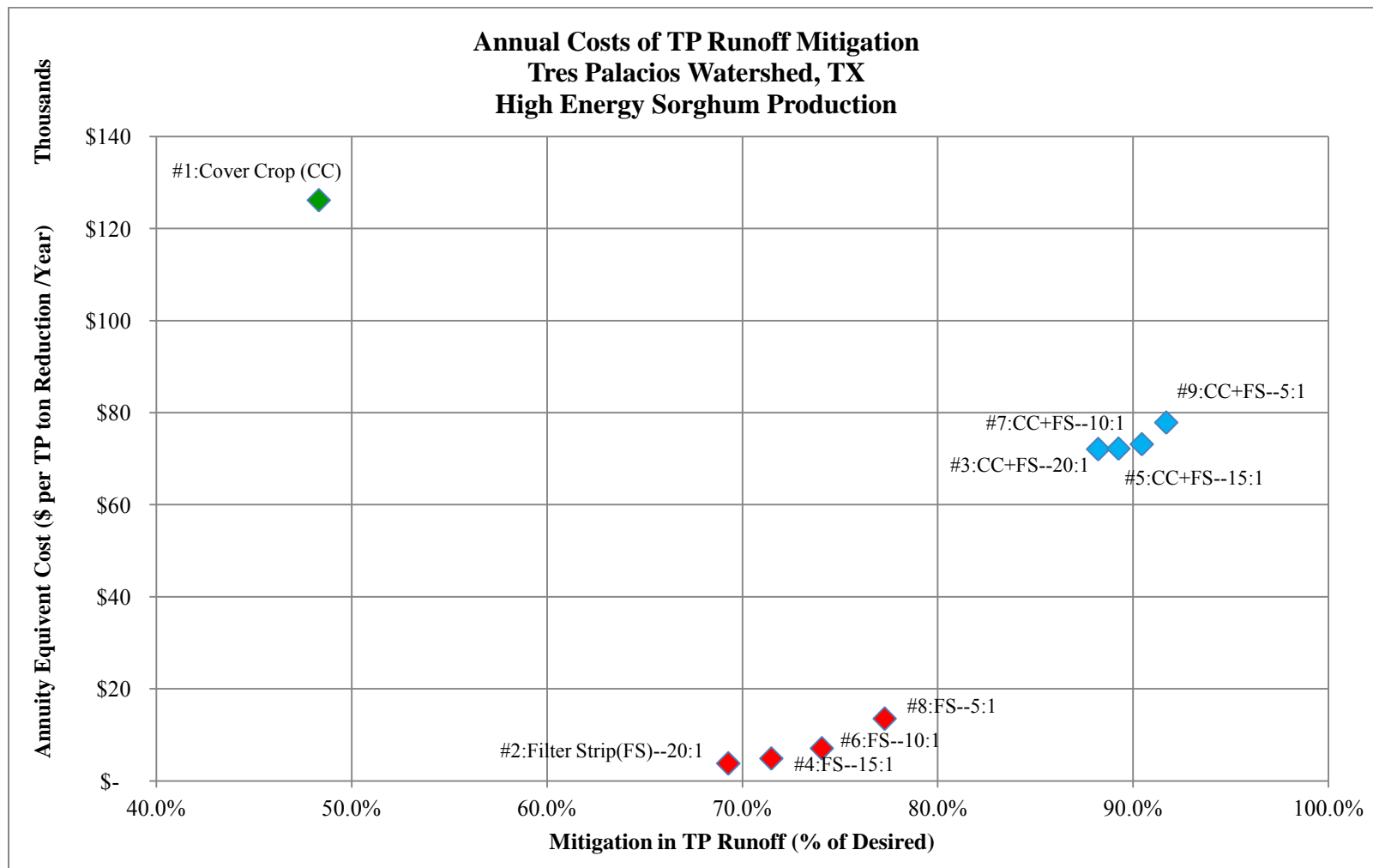


Figure 2-4. Annual equivalent value of costs per ton of total phosphorous reduction and percentage of mitigation in total phosphorous produced by the best management practices evaluated for the Tres-Palacios river watershed, Texas

The cover crop BMP data point on the graph indicates that it is the least cost-efficient BMP compared to filter strips alone and combination BMPs. Filter strips of all intensities produced relatively higher mitigation levels at much lower costs compared to a cover crop BMP. However, the close cluster of filter strip BMPs at the bottom of the graph indicates that investing additional costs for higher intensity in filter strips does not provide significant improvement in TP runoff reduction for the Tres-Palacios River watershed (i.e., the range of improvement is 69.3 percent at \$3,763 per ton for FS (20:1) compared to 77.3 percent at \$13,493 per ton for FS (5:1), figure 2-4 and table 2-8).

The combination BMPs realized approximately 90 percent reduction in TP runoff at an annual cost of approximately \$70,000 per ton. A similar pattern to that realized for the FS of varied intensities is observed in the combination BMPs, i.e., slight improvements in TP runoff reduction at much higher expenditures per unit on an annual basis (i.e., 88.2 percent at \$72,059 per ton for CC+FS (20:1) compared to 91.7 percent at \$ 77,853 per ton for CC+FS (5:1)). These results suggest that marginal improvements in reductions achieved and their associated costs are very critical in evaluation of BMPs for being potential candidates in achieving reductions in nutrient and sediment runoff. In this study, the BMP producing the highest percentage of TP runoff reduction (i.e., CC+FS (5:1)) is associated with a dramatic increase in cost, raising questions as to cost effectiveness. However, as water quality deterioration has wide societal impacts, it is inconclusive on the level of reduction that society might accept when considering cost. Moreover, due to paucity of data and the difficulty to assign responsibilities for

non-point source pollution, an institutional approach to encourage and or mandate BMPs adoption can raise potential challenges.

2.7.2.2 Costs Relative To Acres And High Energy Sorghum Production

Price is a market assignment tool, and failure to account for the costs of externalities in the price of the economic product (ethanol/biofuels in this case) can produce a market failure. Such an effect is an indication that resources can be reallocated to choose an efficient level of activity to make one person better off without making anyone else worse off (Griffin 2006). A variation on this concept is the opportunity to make one much better off compared to the loss of another, or the beneficiary can actually pay to the loser yet still have a net gain. Failure to account for such inefficiency can result in loss of social welfare and sustainability. Sustainability is defined by Asheim (1994) as

“A requirement to our generation to manage the resource base such that the average quality of life we ensure ourselves can potentially be shared by all future generations.”

Hence, it is critical that the decision/policy makers consider the well-being of the future generations as the future generations have the moral right that entail well-being no less than the present. One way to correct this adverse externality involves incorporating the cost of mitigating the unintended externalities into the product price. The value (cost) of the externality is captured in the economic effects and is reported as cost per dry ton of biomass and cost per gallon of ethanol. In addition, the prices per ton of externality

potentially differ widely and are so high that they could make cellulosic biofuels a very expensive alternative for petroleum-based gasoline. Moreover, other social costs such as release of greenhouse gases due to removal of permanent vegetation and tillage operations are excluded in the current evaluation.

For evaluating policies to mitigate externalities, per unit costs to reduce the nutrients and sediment are useful. However, in relating this mitigation policy to a commercial production operation, it is useful to extend the mitigation costs to a per acre basis, per dry ton of biomass, and per gallon of ethanol basis. The cost per acre is based on the total 180,000 acres in the system as well as the 60,000 acres in HES production. The cost per dry ton is based on the production of 510,000 tons of biomass and the cost per gallon of ethanol is based on the then conversion coefficient of 96.5 gallons per ton of biomass and production of 30 million gallons of ethanol. Table 2-9 is a presentation of such estimators.

The marginal per dry ton of biomass and per gallon of ethanol costs are predicated on the hypothetical HES production system identified by McLaughlin (2011a). In McLaughlin's research, the baseline cost of producing HES was \$159.20 per dry ton of biomass and \$2.12 per gallon of ethanol. The estimates identified in this study, taking into account the cost of management practices to mitigate the water quality damages, are interpreted as additions (i.e., marginal) to the estimates identified by McLaughlin (2011a).

Table 2-9. Supply Chain Costs Of Producing HES Per Unit And Mitigation Costs Per Unit Associated With Each Best Management Practice, Tres-Palacios River Watershed, Texas

Supply Chain Costs of Producing Biomass to Supply Feedstock to a 30-Million Gallon Ethanol Facility ^a					
		Costs per Acre of HES Cropping System	Cost per Dry Ton of HES	Cost per Gallon of Ethanol	
		\$ 1,126.61	\$ 159.20	\$ 2.12	
BMP Description	Annuity Equivalent Value of Mitigation Costs (\$/year)	Annuity Equivalent Value of Mitigation Cost			
		Costs per Acre (60,000 acres ^b)	Costs per Acre (180,000 acres ^c)	Costs per Dry Ton of HES ^d	Costs per Gallon of Ethanol ^e
FS (20:1) ^f	\$ 563,862	\$ 9.40	\$ 3.13	\$ 1.11	\$ 0.02
FS(15:1) ^f	751,816	12.53	4.18	1.47	0.03
FS(10:1) ^f	1,127,723	18.80	6.27	2.21	0.04
FS(5:1) ^f	2,255,447	37.59	12.53	4.42	0.08
Cover Crop (CC) ^g	13,185,077	219.75	73.25	25.85	0.44
CC ^g + FS(20:1) ^f	13,748,938	229.15	76.38	26.96	0.46
CC ^g + FS(15:1) ^f	13,939,893	232.33	77.44	27.33	0.46
CC ^g + FS(10:1) ^f	14,312,800	238.55	79.52	28.06	0.48
CC ^g + FS(5:1) ^f	15,440,524	257.34	85.78	30.28	0.51

^a Source: McLaughlin (2011a).

^b Annual HES acreage.

^c Total biomass acres in a three-year rotation.

^d Dry tons per acre yield of HES assumed in this analysis is 8.5 tons per acre (McLaughlin 2011a).

^e The total ethanol production assumed in this analysis is 30 million gallons.

^f FS refers to filter strip BMP and (20:1) refers to the ratio of crop acres to filter strip acres.

^g CC refers to cover crop BMP acres and is assumed to be planted on all land in the rotation that is not planted to HES.

The AEV of mitigation costs noted in table 2-9 correspond to the annual payments necessary to pay for the initial establishment and ongoing operation and maintenance costs associated with each BMP to mitigate the associated runoff from HES biomass production. The AEV of all costs per acre, presented in the column Costs per Acre (60,000 acres) represents the cost per acre of mitigating sediment and nutrient

runoff because of production of 60,000 acres of HES in any point in time.¹³ The cost per acre presented in the column Costs per Acre (180,000 acres) are the calculated costs of mitigating nutrient and sediment runoff based on conversion of 180,000 acres of land from pasture to HES production.¹⁴

The costs presented above only represent the cost of mitigating any associated damages associated with HES crop production (increased runoff of N, P and sediment), but do not account for the costs of production of biomass feedstock. Hence, the total cost of supplying feedstock to a 30-million gallon ethanol facility is estimated as the sum of HES production costs and mitigation costs related to associated runoff. A range of production for HES feedstock is presented in table 2-9, as estimated by McLaughlin (2011a). The cost per acre for mitigating runoff using FS (20:1) alone is \$9.40 for 60,000 acres of HES production. Therefore, the total cost per acre for supplying HES feedstock to an ethanol conversion facility, accounting for production costs and mitigation costs is \$1,136.01 (i.e., sum of \$1,126.61 per acre production costs and \$9.40 per acre in mitigation costs).

The total cost of production of a ton of HES biomass and using the BMP FS (20:1) is \$160.31 (i.e., sum of \$159.20 in production costs and \$1.11 in mitigation costs). The cost per gallon of ethanol, considering the mitigation costs, is in the range of \$0.02 per gallon to \$0.51 per gallon, increasing the pre-refining production cost per

¹³ Recall that in any point in time across all subbasins there are 60,000 acre of HES crop acres.

¹⁴ Recall that there are 180,000 acres of land involved in a three-year rotation, i.e., HES-Fallow-Fallow.

gallon of ethanol from \$2.14 to \$2.63.¹⁵ Although the additional cost per gallon of ethanol is not very high after accounting for the AEV of cost of BMPS, it has to be recognized that mitigation costs are important to consider and contribute to the cost of production of ethanol. Due to these estimates assessing only the cost of mitigating water quality externalities and not accounting for any other social costs, such as loss in recreation due to poor water quality, the cost of ethanol per gallon or any other per unit price does not fully reflect the true price of the economic product.¹⁶ However, prices of ethanol and the associated subsidies that dominate the market provide incentives to expand biofuel production.

2.8 Conclusion

The purpose of this study is to address the issue of the unintended consequences to water quality associated with biomass feedstock production. A hypothetical shift from the current pasture to HES production in the Tres-Palacios River watershed of Texas was evaluated by applying the SWAT model and estimating annual changes in TP, TN, and sediment runoff. The results estimated at the watershed outlet indicate that HES production increases nutrient and sediment loadings.

Cover crop and filter strips were selected as the BMPs to reduce the increased level of runoff of P, N, and sediment from shifting to HES production from pasture. The

¹⁵ The \$2.14 per gallon cost does not account any of the costs involved in conversion of biomass to ethanol. The cost per gallon is estimated as the total production costs of HES divided by 30 million gallons.

¹⁶ It is recognized that accounting for the externality costs transforms private costs to social costs. However, as water quality deterioration is only one externality and there may be other externalities associated with biomass production, the use of the term social cost in the discussion might not be completely justified and hence is not used.

results indicate that the selected BMPs when implemented individually failed to produce reduction levels that meet the status-quo loadings, i.e., pre-HES loadings. The level of mitigation produced in the current analysis through adoption of BMPs are in line with the results from Lee, Narasimhan, and Srinivasan (2011b) and Rister et al. (2009), where similar BMPs achieved the 35 percent reduction goal for TP in the Cedar Creek reservoir, Texas. However, the mitigation level of 100 percent in the current study warrants further evaluation of BMPs. As a result, combination BMPs were evaluated, which produced improved reduction levels, but still fell short of producing the total mitigation, mainly in TP and TN. The sub-par results for the combination BMPs suggest need for evaluation of other potential BMPs such as wetland creation (e.g., construction of a dike around the field). However, it has to be noted that such BMPs can be expensive (Rister et al. 2009).

The results from the SWAT analyses provide a basis for economic analyses, which consists of estimating AEV of all costs of individual and combination BMPs. Two BMPs combined in different ways resulted in nine sets of solutions. These alternatives are used to evaluate the relative cost-effectiveness across the alternatives with the goal to reduce nutrient and sediment runoff, i.e., to get the most “Bang for the Buck.”

The AEV of cost per ET¹⁷ of reduction in TP through Filter strip (20:1) BMP was \$3,763, which is relatively lower than the \$4,752, the AEV of cost per ET of TP estimated by Lee et al. (2010) for the Cedar Creek Watershed. Similarly, the AEV of

¹⁷ ET= English Ton, One ET = 2,000 lbs.

cost per ET of reduction in TP using cover crop BMP was relatively higher in the current analysis compared to Lee et al. (2010) (i.e., \$126,188 compared to \$53,307). The differences in the AEV of BMPs between two studies are primarily attributed to the differences in mitigation levels achieved, which are dependent on topography of the land, rainfall events during the project period, nature of the crop used for the BMPs, history of fertilizer application, etc.

Although the FS (20:1) BMP was substantially less expensive than cover crop BMP, and due to the less than 100 percent mitigation achieved through the individual BMPs, relevant investigation would be to identify the BMPs that can provide the remaining mitigation and their associated costs. As a result, higher intensity BMPs were implemented, i.e., filter strips of intensity FS (15:1), FS (10:1), and FS (5:1). These BMPs produced slight improvements in runoff mitigation at relatively higher costs (i.e., \$13,493 per ET of reduction in TP). A similar trend is observed with the combination BMPs, where the AEV of cost per ET of reduction in TP by CC+FS (5:1) was \$77,853, substantially higher than filter strips BMPs. These results provide interesting insights into the potential of combination BMPS in providing runoff mitigation and their cost-effectiveness.

Considering and accepting all of the assumptions developed in the course of applying SWAT and BMPEconomics, a 100 percent reduction in TP runoff for the case study defined in this research is not achievable. Reference conditions (i.e., pre-HES runoff information) are useful for comparison to the current water conditions (i.e., post-HES with and without BMPs) and to identify the extent of management required to

restore the quality of the resource. An issue to determine is to what extent of improvement is demanded. For example, Rister et al. (2009) identified the portfolio of BMPs for Cedar Creek watershed in Texas to achieve 35 percent reduction in annual TP inflows based on the assumption that a 35 percent reduction would be substantial enough to achieve a local watershed goal. This assumption emphasizes the importance of realistic water management goals and assumptions relative to geographical location. Hence, a more realistic assumption of runoff mitigation levels for the Tres-Palacios River watershed could help identify cost-efficient BMPs and consequently a cost-efficient water quality management plan.

Policies designed around adoption of BMPs to mitigate water quality deterioration are an attempt to make the responsible parties accountable for the costs imposed by their activities (agricultural production in this case). However, in this study, the evaluation of the potential BMPs to achieve status-quo runoff levels (i.e., runoff levels of pre-HES scenario) indicate substantial investment and operation costs. Although achieving status-quo water quality is justified from a societal standpoint,¹⁸ the BMPs selected and their associated costs suggest relatively low levels of protection for inexpensive BMPs and substantial investment and operation and maintenance costs for BMPs that offer higher levels of mitigation. Hence, further investigation of other potential BMPs and reevaluation of the desired mitigation levels are warranted, along

¹⁸Water quality damages can be thought of as a violation of *Pareto Optimality*, where one or more persons are made worse off and the other person/party responsible for the damages better off without compensation to the losing parties, thus resulting in Pareto inefficiency (Griffin 2006).

with evaluation of other economic policy instruments to internalize the water pollution externality.

The costs estimated in this analysis only represent the cost of mitigation of nutrient and sediment, and do not include the production costs of HES.

McLaughlin (2011a) estimated the costs of producing the biomass crop to supply feedstock to a 30-million gallon ethanol facility in Middle Gulf Coast, Edna-Ganado, Texas area. The mitigation costs along with the production costs provide more complete estimate of the pre-refining cost of using a biomass crop for ethanol production. The costs per acre, per dry ton of biomass, and per gallon of ethanol are estimated. The cost per gallon of ethanol, when accounting for the mitigations costs, increased in the range of \$0.02 to \$0.51. These results suggest that mitigation costs contribute to the cost of production of ethanol, therefore, accounting for the mitigation costs is an approach toward internalizing the externality.

If commitment to biofuels production continues, numerous agricultural producers have sufficient incentives to apply greater amounts of fertilizers, cultivate marginal lands, etc., showing little or no regards to environmental consequences. Although BMPs could reduce some of the potential negative impacts, these practices involve costs and can quickly erode the profits of the producers or warrant funding from external sources. Moreover, the current analysis focuses only on the cost side of the BMPs. Identification and estimation of the benefits from water quality protection and comparing against the AEV of all costs will provide a comprehensive estimate of the impact of biomass crop for biofuels. In addition, the U.S. needs to assess the broader environmental issues of

biofuels, not limited to greenhouse gases, to make the biofuels a sustainable option to meet the energy demands of the country. This analysis suggests that decision makers have the responsibility of determining the level of tradeoff between mitigation and costs.

2.9 Limitations

The evaluation of the BMPs to identify a cost-efficient watershed protection strategy for the Tres-Palacios River watershed highlights the important issues that warrant thorough investigation to further improve the analysis. Some of the issues include:

- Water quality modeling requires extensive calibration of nutrient and other runoff data. Calibration of nutrient and sediments was not rigorous in the study due to the unavailability of data at the USGS gauge stations in the watershed region.
- Only two individual BMPs (i.e., cover crop and filter strips) were considered for evaluation in the study. Evaluation of other potential BMPs has the potential for identifying a lower cost solution related to reducing externalities.
- Some existing level of BMPs adoption suited to the current operations is expected in any production enterprise (Rister et al. 2009). However, due to lack of sufficient information to corroborate any such adoption levels in the Tres-Palacios River watershed, a zero current adoption level for the BMPs is assumed.
- It is also appropriate to recognize and include secondary impacts resulting from implementation of the BMPs. For example, the invasive nature of the crops used

for cover crop or filter strips could require additional costs to control their spread to other parts of the watershed. These additional costs could change the portfolio of the BMPs. Due to the associated uncertainty of the secondary consequences, however, these concerns are not included in this study.

- Watersheds are vastly different in terms of soil and land characteristics, thus making the results of this research less generalized and not directly applicable to other watersheds across the U.S.
- Thoughtful consideration should be given to the incentive payments that determine/encourage participation in water quality mitigation activities such as BMPs adoption (e.g., Rister et al. 2009). No such payments were accounted for in the analyses of this research and it was assumed that financial incentives do not play a role in the decision making process of BMPs adoption. Failure to account for such incentive payments most probably underestimates the cost of water quality mitigation, which suggests that the true cost of water quality mitigation can be much higher than what is reported in this research.

3. ESTIMATION OF CROPPING SYSTEM ENERGY BALANCE OF CELLULOSIC BIOFUELS

3.1 Introduction

The potential of ethanol to reduce petroleum use is at the forefront of the energy policy debate. With concerns over projections suggesting continued increase in energy demand and grain ethanol threatening food and feed supplies (Basset et al. 2010), ethanol from biomass is advocated as a possible solution. Perlack et al. (2005) reported that biofuels produced mainly from biomass crops could displace 30 percent of U.S. petroleum consumption by 2030. Although such studies address the issue of non-renewable resource use substitution, they do not always address the notion of overall improvement, i.e., to be a viable substitute for fossil fuel, biofuels should not only have superior environmental benefits, but also produce net energy gain over the energy in the inputs used in their production (Hill et al. 2006).

Typically, studies have used some variant of net energy such as Net Energy Value (NEV), Net Energy Balance (NEB), Net Energy Ratio (NER), etc. to assess the capability of biofuels to substitute for non-renewable energy sources. These energy estimates compare the energy in biofuel to energy in the inputs used during their production (Lorenz and Morris 1995; Pimentel 2001). Several research investigations regarding the net energy of ethanol supply systems emphasize that net energy provides a measure of sustainable energy production (Shapouri, Duffield, and Wang 2002).

While the literature largely suggests that biofuel production has a positive energy balance, the NEV of corn ethanol for several studies indicates negative estimates (figure 3-1). Wide variation in NEV estimates relates to research assumptions, geographic location of crop production, and different data sources used by the researchers. For example, the negative estimates of NEV reported by Pimentel's work is criticized for using obsolete data on crop yields and fertilizer application rates (Shapouri, Duffield, and Wang 2002). Whereas, positive NEV estimates reported by Shapouri were criticized for ignoring energy inputs such as natural gas (Pimentel and Patzek 2005). Moreover, several of the studies in figure 3-1 often lack details of the estimation procedures in their reports.

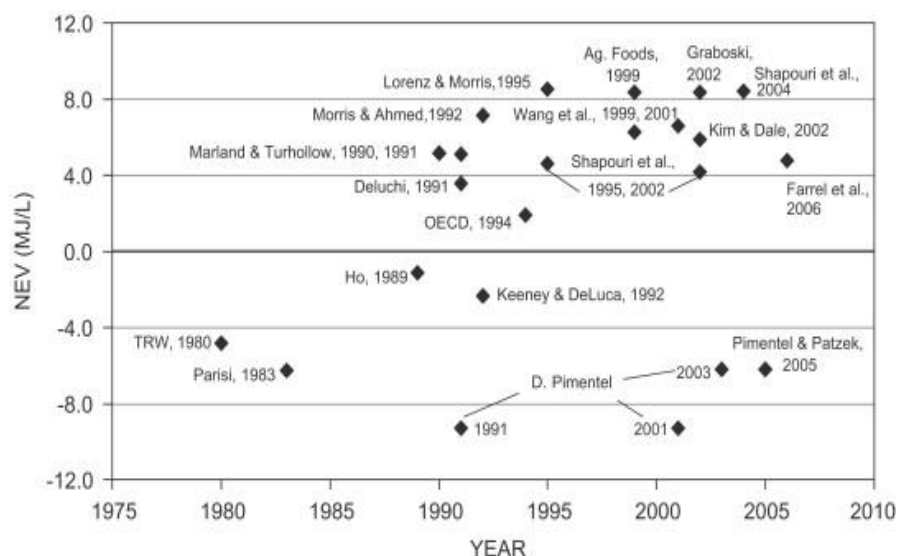


Figure 3-1. Illustration of estimated net energy value of corn ethanol across select literature results

Note: NEV is defined as the difference between the energy content of ethanol and the energy used in producing and distributing it (MathPro Inc. 2005).

Source: U.S. Department of Energy (2007). Refer to the Department of Energy Report for specific references.

Based on the wide varying NEV estimates, it is clear that future analyses must not be limited to reporting NEV, but also focus on utilizing the net energy estimate to address broader policy concerns such as net addition of biofuels to the energy supply of the economy, assessment of the economic competitiveness of biofuels to gasoline, etc.

It is important to identify the potential of an alternative fuel not only from an energy perspective, but also from an economic perspective. Often times, economic approaches are distorted by government intervention through subsidies, tariffs, etc. For example, cellulosic biofuels receive tax credits of \$1.01 per gallon of ethanol (Yacobucci 2012). Such incentives not only distort the energy markets, but also bring into question the economic competitiveness of the biofuels in the absence of such tax incentives. Considering the energy priorities that place importance on energy security, energy assessment metrics such as NEV or a similar energy variant are necessary to understand the significance of implementing various renewable feedstocks alternatives, mainly in terms of the nature of energy used and produced and net amount of transportation fuel produced.

3.2 Objective Of The Study

As alternative feedstocks for biofuels emerge, it is important to assess the criteria of net energy gain as it provides an evaluation of the potential of such feedstocks as sustainable alternatives to fossil fuels. Considering the energy policies that promote biomass feedstocks as potential energy crops, it is important that such alternative fuels not only have a net energy gain, but that they also are produced in sufficient quantities. Determining whether biomass-based fuels provide energy gain over the inputs used in

their production requires a thorough accounting of the direct and indirect inputs and outputs. The specific objectives of the study include:

- Estimate the NER of biomass ethanol using production data of dedicated biomass feedstocks, mainly Switchgrass (SG) and High-Energy Sorghum (HES) produced in the Middle Gulf Coast, Edna-Ganado, Texas to supply feedstock to a 30-million gallon ethanol conversion facility.
- Estimate the net amount of biofuel energy produced by taking into account the NER of each of the dedicated biomass crops.
- Estimate the cost per gallon of ethanol accounting for the production costs, mitigation costs, and energy estimates derived in this study.

3.3 Literature Review

The energy balance of biofuels debate began in mid-70's and continues today. Numerous studies quantified the energy consumption in agricultural production (Heslop and Bilanski 1989; Swanton et al. 1996) and categorized input use for operation of machinery, irrigation, manufacture of fertilizer, transportation, etc. The U.S. Department of Agriculture (2005) reported fertilizer and fuel account for more than half of the total energy consumed on U.S. farms, suggesting they form the primary components in the NER estimation. This magnitude of importance is also evident in figure 3-2, where the percentages of energy consumption associated with the inputs involved in production on U.S. farms for the year 2002 are reported. This indicates that fertilizers and fuel account for more than 90 percent of the energy consumed on farms.

McLaughlin and Walsh (1998) estimated that SG when grown as a biomass crop produced 300 percent more energy than consumed during its production. However, the study does not report the source of data for switchgrass production. To avoid any such conflicts regarding production data, the estimation of NER in this paper is based on the input and output data from a hypothetical crop production enterprise that produces biomass crops to supply feedstock to a 30-million gallon ethanol facility in Middle Gulf Coast, Edna-Ganado, Texas area (McLaughlin 2011a). Such an approach also helps to maintain consistency with the input use, which can differ by region because of seasonal variations (Schmer et al. 2008).

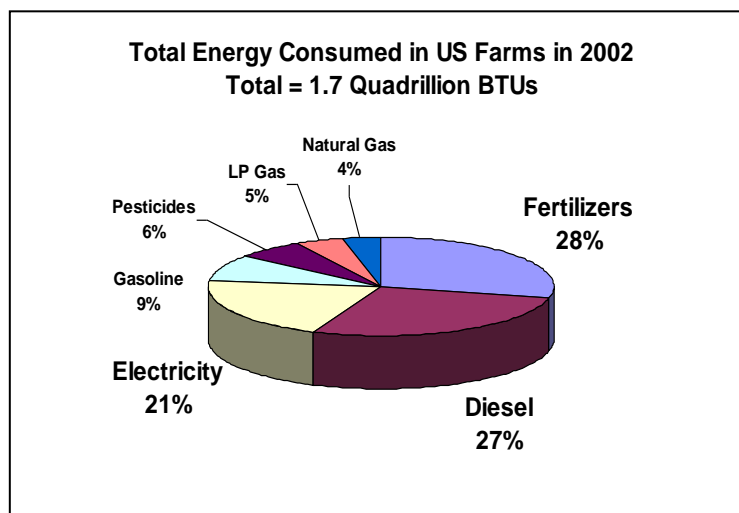


Figure 3-2. Energy consumption by farm inputs involved in the production on U.S. farms as a percentage of total energy consumed by the agricultural sector for the year 2002
Source: Miranowski (2004).

With biofuel mandates and associated subsidies potentially influencing decisions to produce biomass crops and affecting the profit margins for ethanol processing plants, biomass crop production is expected to extend to non-biofuel growing areas, affecting

cropping patterns across the U.S. The current analysis estimates the energy return of biomass ethanol produced from SG and HES crops grown on land previously in pasture. Blottnitz and Curran (2007) reported that crop production on marginal lands requires relatively greater amount of inputs compared to production activities on traditional cropland. Decisions to produce biomass crops on land previously under pasture are expected to influence input use on farms and consequently, NER of biomass ethanol.

Seawright et al. (2010) estimated energy balance of irrigated corn ethanol in Texas High Plains (THP) and identified a negative energy balance. The report also indicates that irrigated corn production in THP consumes more energy than average U.S. corn production, suggesting that energy balance can change in accordance with factors such as geographical location, type of production system (e.g., dryland versus irrigated), kind of feedstock, etc. The current analysis that estimates the NER of biomass ethanol produced from SG and HES feedstocks grown in the Middle Gulf Coast, Edna-Ganado, Texas area is useful to analyze whether such an impact manifests in associated NER estimates. Despite all of the potential issues and challenges associated with the energy return of ethanol, it is still an important measure to evaluate the potential of a proposed energy source to stand on its own and make an independent contribution to the U.S. energy supply.

3.4 Methodology

The continuing public debate regarding biofuels is the driving force for this research. As alternatives for conventional fuel emerge, it is important to assess whether or not more energy is produced than consumed in the production of such alternative

fuels. The energy to grow, harvest, transport, and process the biomass crop is compared against the energy contained in the crop to obtain an estimate of the NER of biomass ethanol. Unlike corn, where data on grain yield and agricultural inputs are readily available, data on bioenergy crops are limited (Schmer et al. 2008). Hence, relevant field-scale information for SG and HES managed as bioenergy crops was obtained from McLaughlin (2011a).

3.4.1 Energy In Biomass/Output

The first step in the energy return estimation of biomass ethanol is to identify the number of gallons of ethanol produced from a ton of biomass, referred to as the conversion coefficient (C-C). Due to lack of fully operational cellulosic ethanol plants, estimates of ethanol yield from biomass are obtained from the literature. The C-Cs of biomass crops vary widely among studies, ranging from 71.3 to 100.0 gallons per ton of biomass. Hence, the C-C for biomass crops is estimated using a simple average. The C-C was estimated at 96.5 gallons per ton of biomass, which when multiplied by the heat value of ethanol (i.e., 83,333 British Thermal Unit (BTU) per gallon of ethanol (Energy Information Administration 2012)) provides an estimate of the total energy contained in a ton of biomass. That is, it is estimated in this study that a ton of biomass is equivalent to 8,041,634.5 BTU. This total energy in output is compared against the energy in the inputs used to produce the biomass crop, thus producing the net energy estimate of the biomass ethanol.

3.4.2 Energy In Crop Production Inputs

Fuel and fertilizer inputs account for more than half of the on-farm input use, (figure 3-2). The on-farm inputs selected for this study embody mainly primary inputs that are a combination of direct and indirect energy inputs. Direct energy inputs in agriculture are primarily fossil fuels used to operate machinery for land preparation, planting, fertilizer and chemical applications, irrigation, and transportation of inputs and outputs; whereas, indirect energy embodies energy required to manufacture and transport inorganic fertilizers, chemicals, seed, etc. (Economic Research Service 1994). The other category of inputs used on-farm are the secondary energy inputs that include energy required to build machinery, vehicles, conversion facilities, etc. Secondary input use is not only difficult to quantify, but it also accounts for very little energy on a per gallon basis (Shapouri, Duffield, and Wang 2002). Hence, the current analysis does not account for any of the secondary inputs, but instead uses only the primary energy inputs in the estimation of the NER for biomass ethanol.

3.4.2.1 Energy In Fertilizer Inputs

The energy components of fertilizer inputs mainly include energy required to manufacture and apply the fertilizers to the crop. The data regarding the type of fertilizer and application rates of fertilizers for SG and HES production systems are reported in McLaughlin (2011a). Pradhan et al. (2008) reported that, as raw materials are mainly derived from fossil fuels for fertilizer manufacture, the energy content of the fossil fuel could be used as an estimate of the energy content of the fertilizer. For example, natural gas is the primary feedstock in manufacturing of nitrogen fertilizer.

Hence, the energy content of the natural gas is used as an estimate of the energy content of the nitrogen fertilizer. The current analysis adopts Gellings and Parmenter (2004) estimates of the energy required to produce, pack, and transport the fertilizer by nutrient type (table 3-1).

Table 3-1. Average Fossil Fuel Requirements To Produce, Package, And Transport Fertilizer By Nutrient Type On A Per Unit Basis

	Energy Requirement, BTU/lb		
	Nitrate	Phosphate	Potash
Produce	29,899	3,313	2,753
Package	1,119	1,119	774
Transport	1,936	2,452	1,979
Total	31,954	6,884	5,506

Source: Gellings and Parmenter (2004).

Estimates in the table 3-1 indicate that 31,954 BTU, 6,884 BTU, and 5,506 BTU of energy are required to produce, pack, and transport a pound of nitrate, phosphate, and potash fertilizer, respectively. These energy values multiplied by the amount of fertilizer applied per acre on SG and HES systems produce an estimate of the total on-farm fertilizer energy use. The amount of fuel used to apply fertilizers to the crop is accounted in the fuel energy inputs and is addressed in the next section.

3.4.2.2 Energy In Fuel Inputs

Diesel fuel is the primary fuel for all the crop operations for SG and HES production system in McLaughlin (2011a). Diesel is used for a variety of operations related to crop production such as planting, fertilizer and herbicide application,

irrigation, etc. The amounts of diesel fuel used for all SG and HES crop operations are 10.9 and 45.9 gallons per acre, respectively. These fuel use values multiplied by the heat value of the diesel fuel (i.e., 135,567 BTU per gallon, as reported by Energy Information Administration (2009)) produce an estimate of the on-farm fuel energy use. The amount of energy required to extract, refine, and transport fossil fuels is not included in the current analysis primarily due to lack of literature. Moreover, Graboski (2002) reported that such energy's contribution to the energy use per acre or per unit of biofuel produced is very small, justifying the assumption that such an approach of not accounting for secondary energy inputs has only a minimal effect on the energy estimate of biomass ethanol.

3.4.2.3 Energy In Seed Input

The seed energy refers to the energy consumed in the production of the seed. Seed energy values for both SG and HES are obtained from Schmer et al. (2008) and are approximately 19,347 BTU per pound of seed, i.e., approximately 19,347 BTU equivalent of energy is used to produce a pound of seed. Seeding rate for SG and HES are obtained from McLaughlin (2011a) and are 8.0¹⁹ and 7.0 pounds per acre, respectively. The seeding rate and the associated energy values are used to estimate the on-farm energy use in terms of seed.

¹⁹ SG is a perennial grass and it is expected that the stand will have a life of 10 years (McLaughlin 2011b). Hence, seeding is done only in year one, the establishment year. Therefore, the amount of energy content in SG seed is amortized over 10 years.

3.4.2.4 Energy In Ethanol Conversion

The information available on energy used in conversion facilities to transform biomass into ethanol on a commercial scale is not as extensive as corn ethanol. Hence, the energy inputs associated with conversion facilities are based on the literature, with the assumption that they do not greatly influence the total energy calculations for the biofuel production enterprise in the Middle Gulf Coast, Edna-Ganado, Texas Area. Pimentel and Patzek (2005) reported an estimated energy use of 6,135 BTU per gallon of ethanol produced from biomass. This conversion energy input along with on-farm energy inputs are used in the estimation of the NER of biomass ethanol.

3.5 Results

The primary goal of this study is to estimate the energy efficiency of biomass ethanol in terms of NER, where the total amount of energy required per acre to produce SG and HES are compared against their energy content. Table 3-2 is a summary of the results for SG and HES production systems and the corresponding energy content. The factors that contribute to the apparent differences are also addressed in this section. “Unit per Acre” column in table 3-2 identifies the output and input quantities for SG and HES on a per acre basis. For example, SG crop requires 60 lbs of nitrogen per acre, whereas HES requires 240 lbs of nitrogen per acre. The remaining entries in the “Unit per acre” column are interpreted in a similar manner.

Parrish and Fike (2005) reported that biomass crops require significant annual nitrogen fertilizer to produce higher yields. The fertilizer application levels in McLaughlin (2011a) are relative to the yield levels of crop, where N, P, and K in the

amounts of 60, 20, and 40 lbs per acre, respectively, for SG are relative to a yield level of 3.0 dry tons per acre. Whereas, for HES fertilizer levels of 240, 80, and 160 lbs per acre of N, P, and K are relative to a yield level of 12.0 dry tons per acre²⁰. As a result, SG production required fertilizer energy input of approximately 2.27 million BTU per acre, while HES production required 9.10 million BTU per acre (table 3-2). The percentage of energy consumed in terms of fertilizers in the current analysis is substantially greater than the estimates reported in literature. For example, Miranowski (2004) reported that fertilizer accounts for 27 percent on total on-farm energy use; however, the estimate in the literature is an average across U.S. farms. The high percentage of fertilizer energy use in the current analysis is primarily due to the application levels relative to the yield of the crop.

“BTU per Unit” column indicates the amount of energy in a unit of a product, i.e., 31,954 BTU of energy is present in a pound of nitrogen fertilizer, which when multiplied by per acre applied rate produces the energy content on a per acre basis. Finally, “BTU per Acre” column indicates the total energy in each input on a per acre basis, i.e., 1,917,240 BTU per acre for SG indicates the total on-farm energy used in terms of nitrogen fertilizer, which is estimated by multiplying the 31,954 BTU by the 60 lbs of nitrogen fertilizer applied per acre for SG production system.

Recall that SG is a perennial grass and is expected to have a life of 10 years, whereas HES is an annual grass. As a result, SG is only planted in year one. Hence, the

²⁰ Although 3.0 dry tons per acre and 12.0 dry tons per acre yield are considered possible for SG and HES, respectively, only an average yield of 2.69 and 8.50 dry tons per acre are realized for SG and HES, respectively, due to varied planting and harvesting dates, to minimize costs of production (McLaughlin 2011a).

energy content of SG seed is amortized over 10 years to reflect the 10-year life of the SG crop, evident from lower energy content for SG seed compared to HES (i.e., 15,477 for SG seed compared to 135,429 for HES seed).

Table 3-2. Output Per Acre, Input Use Per Acre, Energy Content Of Output And Inputs Per Unit, Total Energy Per Acre, And Net Energy Ratio Associated With SG And HES Production In The Middle-Gulf Coast, Edna-Ganado, Texas

Item	Unit/Acre ^a		BTU/Unit	BTU/Acre	
	SG	HES		SG	HES
Yield (A)	2.7 tons	8.5 tons	8,041,634	21,631,995	68,353,889
Seed	8.0 lbs	7.0 lbs	19,347 ^{c, d}	15,477 ^b	135,429
Fertilizer^e					
Nitrogen	60.0 lbs	240.0 lbs	31,954	1,917,240	7,668,960
Phosphorous	20.0 lbs	80.0 lbs	6,884	137,680	550,720
Potash	40.0 lbs	160.0 lbs	5,506	220,240	880,960
Herbicide					
2,4-D ^f	2.5 pt	-	36,254	90,635	-
Bicep	-	2.0 pt	45,381	-	90,762
Fuel					
Diesel fuel	10.9 gal	45.9 gal	135,567	1,477,680	6,222,525
Total Crop Input Energy				3,858,952	15,549,356
Energy for Biomass Conversion ^g	259.5 gal	820.2 gal	6,135	1,592,554	5,032,234
Total Input Energy (B)				5,451,506	20,581,590
Net Energy Ratio (A/B)				3.96	3.32

^a Source: McLaughlin (2011a).

^b Switchgrass is a perennial crop and is expected that the stand will have a life of 10 years. As a result, seeding takes place in year one, i.e., the establishment year. Therefore, the energy content of the SG seed is amortized over a 10-year period.

^c The energy content of the SG seed is available from Schmer et al. (2008).

^d The energy content of the HES seed is available from Bonari et al. (1992).

^e Fertilizer application rates are relative to the yield of the biomass crop and are applied in 3:1:2 ratio (Blumenthal 2011 in McLaughlin 2011a).

^f Source: Green (1987), and 1 pt = 1 lb.

^g Source: Pimentel and Patzek (2005).

Figure 3-3 presents the percentage of energy consumed in terms of each input for SG and HES production systems. For example, the estimates in figure 3-3 indicate that SG seed account for 0.4 percent of the total energy and HES seed accounts for 1.0 percent of the total on-farm energy. The energy related to other inputs on a percentage basis is similar for SG and HES.

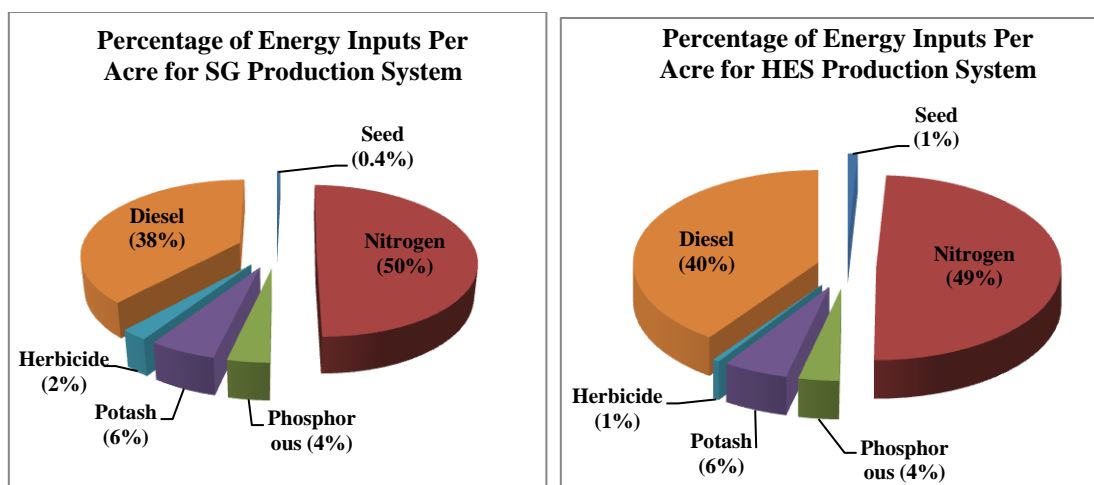


Figure 3-3. Energy consumption by farm inputs as a percentage of total energy consumed involved in the production on switchgrass and high energy sorghum grown in the middle-gulf coast, Edna-Ganado, Texas to supply feedstock to a 30-million gallon ethanol facility

The energy input associated with herbicide use was similar for both feedstocks, i.e., 90,635 BTU per acre for SG and 90,762 BTU per acre for HES. Although the physical amount of herbicide used is small, herbicides have relatively greater energy input per pound of product compared to fertilizer inputs (i.e., 36,254 BTU per unit for 2,4-D compared to 31,954 per unit of nitrogen fertilizer), and account for 1.0 percent and 2.0 percent of the production energy used for SG and HES, respectively (figure 3-3).

On-farm diesel fuel energy is the second largest energy input (table 3-2, figure 3-3). The use of diesel fuel throughout the production phase resulted in energy

estimate of 1.48 million BTU per acre for SG and 6.22 million BTU per acre for HES. The difference in diesel fuel use between SG and HES is primarily due to the additional fuel used for pumping irrigation water in the HES production system. Other forms of fuel inputs such as gasoline, electricity, etc. were not included in the analysis, as data on these energy inputs were difficult to quantify from McLaughlin's (2011) study.

Although the data on an operational cellulosic ethanol plant are limited, Pimentel and Patzek (2005) reported energy values associated with conversion facilities, which indicates that it takes 6,135 BTU to produce a gallon of ethanol at a conversion facility. This energy estimate along with the energy use for the farm production phase of SG and HES biomass provides an estimate of the energy consumed per acre to produce biomass and convert to ethanol.

Accounting for the total on-farm energy inputs and the energy used in conversion process, the total input energy for SG and HES are 5.45 and 20.58 million BTU per acre, respectively. The total energy in the inputs and the energy in the output are used to estimate the NERs of biomass ethanol, which are determined to be 3.96 and 3.32 for SG and HES, respectively. These estimates indicate the energy output of the final biofuel product to the energy used to produce the biofuel, i.e., every unit of energy spent in SG biomass production and conversion to ethanol produces 3.96 units of biomass ethanol energy. According to the results, SG produced more net energy than HES. However, on a BTU basis, the net amount of BTU produced from SG to ethanol is approximately 16.2 million (21.6 million less the 5.4 million BTU, table 3-2) and net BTU from HES to

ethanol is 48 million. The net BTU is estimated by subtracting the BTU in ethanol from the BTU in total energy inputs.

3.6 Policy Implications

The Energy Independence and Security Act (EISA) of 2007 implemented a Renewable Fuel Standard (RFS), requiring production of 36 billion gallons of renewable fuels by 2022, with 21 billion gallons produced from biomass (Renewable Fuel Association 2010). This magnitude of production of U.S. biofuels is expected to replace 7.0 percent of the nation's expected annual gasoline consumption (Renewable Fuels Association 2010). While the production of biofuels may be politically and economically attractive, the most pressing energy policy issue is the net availability of renewable fuels.

3.6.1 Net Supply Of Biofuels

This section examines the net biofuel production taking into account the NERs of SG and HES estimated and presented in table 3-2. The net energy ratio, is useful to gauge the technical efficiency of inputs required in ethanol equivalents to produce a gallon of ethanol. Three potential biofuel mandates are evaluated (i.e., 16, 20, and 36 billion gallons of biofuels) to identify the net amount of biofuels produced accounting individually for the NER of SG and HES (figure 3-4).

The estimates in the graph indicate that production of 16 billion gallons of biofuels, considering the 3.96 NER of SG and assuming only SG as a potential biomass feedstock, results in a net energy addition of 11.95 billion gallons of biofuels. This net

addition to U.S. energy indicates that input energy equivalent to 4.04 billion gallons of ethanol was used to produce, transport, and convert SG biomass to biofuels²¹. The net production of 11.95 billion gallons of ethanol suggests that the production mandate of 16 billion gallons contributes only a 75 percent in net supply. These results are primarily based on the production characteristics of McLaughlin (2011a) being applicable across all U.S. land areas.

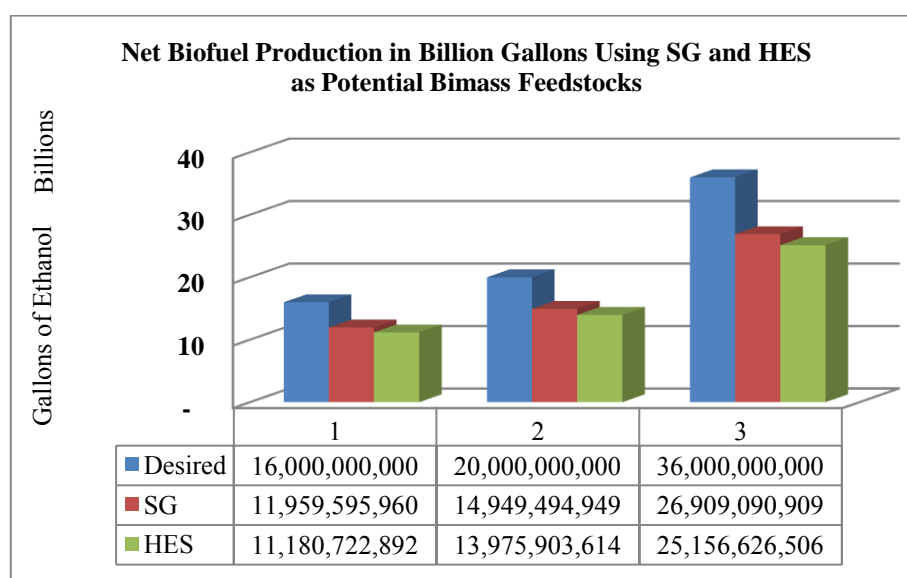


Figure 3-4. Net biofuel production from biomass feedstocks taking into account the net energy ratio associated with each of the biomass feedstocks, switchgrass and high energy sorghum in this case

Similarly, considering the 3.32 NER of HES feedstock, production of 16 billion gallons of ethanol results in a net production of 11.18 billion gallons of biofuels, indicating that input energy equivalent of 4.82 billion gallons of ethanol are used during production, transportation, and conversion of the crop, suggesting an approximate

²¹ Net Biofuel production using SG is estimated as: $(16,000,000,000 / 3.96 = 4,040,404,040)$;
 $16,000,000,000 - 4,040,404,040 = 11,959,595,960$.

contribution of only 70 percent in net supply. The other biofuel scenarios are interpreted in a similar manner.

Across the scenarios, SG produces a slightly higher net amount of biofuels compared to HES, primarily due to the relatively-higher NER associated with SG. These results suggest that large-scale biomass production that is expected to contribute to the U.S. energy supply poses potential issues with regard to the net addition to U.S. fuel supply. This suggests that policies that propose alternative renewable fuels should evaluate not only the economic consequences of alternative fuels but also the increase in net amount of fuel supply to the U.S. energy supply. For example, Adusumilli et al. (2010) estimated that the production of 36 billion gallons of corn ethanol results only in 25.4 billion gallons of net increase, a 70 percent addition to the net supply.

3.6.2 Cost Of Gallon Of Ethanol

Cellulosic fuels have been identified by U.S as a means to enhance security of the U.S energy supply. These alternative fuels are projected to supply 30 percent of the nation's current petroleum consumption (Perlack et al. 2005). However, the economic competitiveness of biofuels is significantly affected by their production costs.

McLaughlin (2011a) estimated the economic and financial costs of producing both SG and HES to supply feedstock to a 30-million gallon ethanol facility in Middle-Gulf Coast, Edna-Ganado, Texas. His results indicated that just production, harvesting, and transport of the biomass costs range from \$2.12 per gallon to \$1.17 per gallon of ethanol equivalent for HES and SG, respectively.

The current analysis extends the economic impacts to reflect the net energy associated with the cellulosic biofuels in the cost per gallon of ethanol. The total production costs of SG and HES estimated by McLaughlin (2011a), the conversion cost of biomass to ethanol²², and the net amount of biofuels estimated in the current analysis are then used to estimate the cost per gallon of ethanol. Table 3-3 summarizes the net amount of biofuel produced and the cost per gallon of ethanol accounting for the NER of biomass crops.

Table 3-3. Summary Of The Production Costs, Net Amount Of Biofuel Produced, And The Cost Per Gallon Of Ethanol Accounting For The Net Energy Ratio Estimates

	SG	HES
Desired Ethanol Production (gallons) ^a	30,000,000	30,000,000
Production Costs (\$/year), to Supply Feedstock to Meet the Desired Ethanol Production ^a	\$ 35,300,000	\$ 63,700,000
Conversion Costs of Biomass to Ethanol, conversion cost of producing 30-million gallons	\$ 51,467,594	\$ 51,467,594
Net Energy Ratio ^b	3.96	3.32
Net Biofuel Production (gallons) ^c	22,424,242	20,963,855
Ethanol Cost (\$/gallon) ^d	\$ 1.17	\$ 2.12
Adjusted Cost of Ethanol (\$/gallon) ^e	\$ 3.87	\$ 5.49
Increase in Ethanol Production Cost (\$/gallon) accounting for NER ^f	\$ 2.70	\$ 3.37

^a Source: McLaughlin (2011a).

^b Refer to table 3-2 to identify the Net Energy Ratio.

^c Net Biofuel Production Using SG: $(30,000,000/3.96 = 7,575,758; 30,000,000 - 7,575,758 = 22,424,242)$.

^d $35,300,000/30,000,000 = \1.17 ; similar estimation for HES.

^e $35,300,000/22,424,242 = \1.57 .

^f $\$1.57 - \$1.17 = \$0.40$, and $\$3.03 - \$2.12 = \$0.91$

²² The current analysis accounts for the energy used in conversion process of biomass to ethanol and hence is important to account for the cost of conversion of biomass to ethanol at a conversion facility. Due to the same reasons of lack of information on the cellulosic processing plants, the cost of conversion of corn to ethanol is used as a proxy for the conversion costs of biomass to ethanol. The cost of conversion of biomass to ethanol is \$1.71 per gallon of ethanol (Pimentel and Patzek 2005).

The results from table 3-3 indicate that to produce 30 million gallons of ethanol using HES, input energy equivalent to 9.03 million gallons of ethanol is required, thus resulting in a net production of 20.9 million gallons of ethanol. As a result, accounting for the 3.32 NER of HES and the net amount of biofuels produced, the cost per gallon of ethanol increased by \$3.37 from \$2.12, making the total cost of production of a gallon of ethanol \$5.49, which is substantially higher than the \$2.00 per gallon production cost of gasoline (U.S. Census Bureau 2005). SG estimates are interpreted in a similar manner. These results suggest that even though cellulosic ethanol benefits from the \$1.01 tax credits (Yacobucci 2012), the cellulosic ethanol produced from HES remains at a cost disadvantage compared to gasoline. Recall that the cost per gallon of biomass ethanol presented in table 3-3 does not account for the cost of mitigation of unintended environmental externalities, which when included would add to the production cost of cellulosic biofuels, making them more economically inefficient.

Biofuel initiatives resulting in shifting of current cropped acres, pastureland, and conservation acres across the country toward corn and other cellulosic biofuel crops could demand increased application of chemicals and fertilizers (Simpson et al. 2008). Such management decisions can produce unintended environmental consequences such as water quality deterioration. One way to internalize the resulting externalities is to incorporate the cost of mitigation in the product price, i.e., ethanol. Chapter one of this dissertation estimates the annuity equivalent costs of Best Management Practices (BMPs) to mitigate water pollution externalities because of biomass production. These annuity equivalent values reflect the cost of mitigating the externality and are captured in

the economic effects through the per gallon production cost of ethanol. The additional cost per gallon of ethanol for several degrees of mitigation in water quality damages is reported in chapter one, with the additional cost per gallon of ethanol equal to \$0.02 for minimum nutrient runoff mitigation and \$0.51 for approximately 100 percent mitigation.

The current analysis accounting for the mitigation costs associated with the Least-Mitigation and the Most-Mitigation scenarios presents the additional cost to produce a gallon of ethanol that already incorporates the production costs and energy return adjustments (figure 3-5). The Least-Mitigation scenario is associated with the annuity equivalent value of all costs of BMPs producing minimum mitigation.²³ The Most-Mitigation scenario is associated with the annuity equivalent value of all costs of BMPs producing maximum amount of mitigation.

Figure 3-5 summarizes the total cost per gallon of ethanol produced from an HES biomass crop taking into account the production costs, net energy ratio, and the mitigation costs.²⁴ These results provide interesting insights regarding the process of production of ethanol and their contribution to the cost of the final product. The cost of gallon of ethanol is approximately \$5.51 under Least-Mitigation scenario and \$6.00 under the Most-Mitigation Scenario.²⁵ Although mitigation costs account for very little in the Worst-Case scenario, the social costs of allowing water pollution is not captured in

²³ Chapter one of the dissertation presents a detailed version of water quality externality because of biomass production, and the associated Annuity equivalent value of costs of BMPs to mitigate the externalities.

²⁴ Chapter one of the dissertation presents the water quality damages associated with only HES, hence, the results for the cost per gallon of ethanol are limited to HES.

²⁵ The cost per gallon estimated in table 3-3 and in figure 3-5 is not directly comparable to the price per gallon of ethanol at the pump, as the cost estimated in the current analyses does not account for the taxes, subsidies, etc.

the cost of ethanol, suggesting that the cost per gallon of ethanol reported in the current analysis does not completely reflect the cost of production of ethanol from biomass crops.

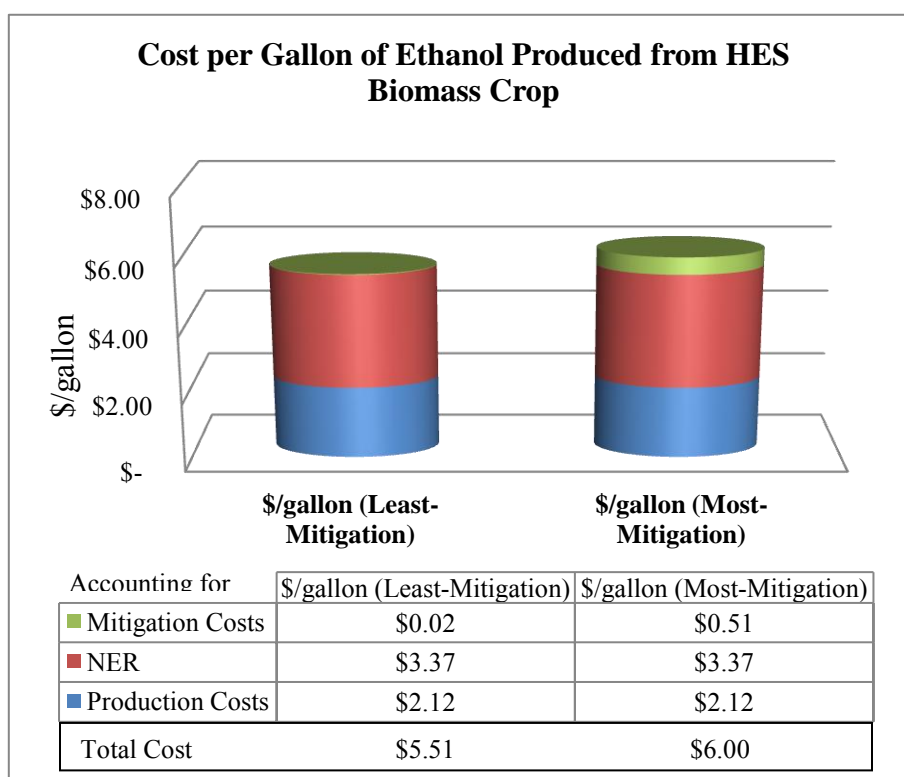


Figure 3-5. Cost per gallon of ethanol produced from high energy sorghum biomass crop, accounting for the production costs, net energy ratio, and the mitigation costs

U.S. has shown strong interest in the development of biofuels. Debate may continue on the net energy of grain and cellulosic biofuels, industry's potential to meet the growing U.S. energy demand, and the potential of biofuels to compete with conventional fuels. The results from this study indicate that energy estimates for commercial production of cellulosic biofuels vary widely. Moreover, the results from this study are contrary to the claims of several reports that cellulosic biofuels are low-

cost non-food feedstocks that are environmentally beneficial (Farrell et al. 2006; Hill et al. 2006). In addition, accounting for the energy estimates and the costs to mitigate the potential environmental externalities shows that cellulosic biofuel are not economically competitive with the conventional fuels and raise concerns regarding the potential of biofuels to meaningfully offset the U.S. petroleum imports.

3.7 Conclusion

The limited potential of grain-based biofuels to provide energy-efficient alternatives to substitute fossil fuels paved the way for the cellulosic-based biofuels. The cellulosic biofuels were introduced with the notion that they are less input intensive and result in better energy balances. However, limited attention was given to evaluate the efficiency of such biofuels.

In this paper, NER was estimated to evaluate the efficiency of various cellulosic feedstocks primarily proposed to produce biofuels. The production data analyzed from McLaughlin (2011a) resulted in a NER of 3.96 and 3.32 for SG and HES, respectively. The results from the current analysis indicate a slightly higher net energy associated with biomass crops compared to the net energy for SG estimated by McLaughlin and Walsh (1998). Their results indicate a 3.0 net energy for cellulosic ethanol produced from SG. The difference in the estimates between the two studies is primarily attributed to the energy associated with the secondary inputs, which are not considered in the current analysis due to outdated nature of the data. However, studies that are more recent indicate energy return for SG in the range of 7.0 (Schemer et al. 2008). Although the data inputs in their analysis and the current analysis are similar, it

has to be recognized that energy return varies by region as do production activities used to grow, harvest, and process feedstocks.

Although SG and HES are considered potential alternative energy feedstocks based on the energy return estimates, the pressing policy issues include net addition of fuel supply to the economy, the cost per net gallon of ethanol, etc. The NER of biomass crops is used to estimate the amount of energy required in ethanol equivalents to produce a gallon of ethanol. Evaluating each feedstock independently, a policy scenario targeting production of 16 billion gallons resulted in a net production of 11.95 and 11.18 billion gallons of ethanol using SG and HES, respectively. Often, the energy required that goes into production and conversion of feedstock are ignored leaving the impression that more fuel is added to the energy supply. However, the current analysis suggests that only 70 percent of the proposed biofuel production mandates are added to the energy supply when accounted for the energy embedded in the inputs used in the production of biofuels.

Moreover, the cost per gallon of ethanol taking into account the net amount of biofuel supplied through production of SG and HES resulted in an increase of \$2.70 and \$3.37 per gallon, respectively, beyond the biomass production costs. As a result, HES ethanol costs are greater than the cost of production of a gallon of gasoline. These results suggest that cost of production of cellulosic biofuels is not at a level to make them competitive with gasoline, as indicated by Bracmort et al. (2010) as one of the potential challenges of renewable fuels.

Production of biomass crops is also associated with unintended environmental consequences, such as water quality deterioration. The current analysis also evaluates the effect of internalizing the water quality produced through biomass crop production on the cost per gallon of ethanol. The results indicate that the cost of ethanol increases by \$0.02 per gallon for minimum mitigation and by \$0.51 per gallon for approximately 100 percent mitigation, bringing the total cost to produce a gallon of ethanol in the range of \$5.49 to \$6.00 using HES as a biomass crop. These estimates reflect that production costs of ethanol are substantially higher than the National Renewable Energy Laboratory's (2007) estimate of \$2.40 per gallon to produce and convert cellulosic feedstock to ethanol, renewing concerns of critics regarding the potential of cellulosic biofuels as a viable alternative to U.S energy demand.

All of these factors confirm that estimation of NER provides valuable information to evaluate the potential of biofuels as alternative source of energy. Although energy return estimation is only one of the assessment metrics, broader impact-based metrics are required to provide information to the decision makers regarding other critical issues. While the governments continue to support ethanol development to enhance energy security, attention must be given to develop a strategic plan to promote biofuels, accounting for the potential concerns at local, regional, and national levels.

3.8 Limitations

Some of the limitations associated with the current analysis of estimation of energy return of biomass-based ethanol include:

- The current analysis omits any energy required to produce machinery, farm equipment, conversion facilities, etc. as the energy estimates associated with these inputs is old and outdated. Availability of contemporary energy estimates for these inputs would allow for development of a more comprehensive energy estimate for cellulosic biofuels.
- Limited to no information was available regarding the co-products associated with biomass crops. As a result, no energy or value was assigned to the co-products in the NER estimation of biomass ethanol, thereby underestimating the benefits of biomass ethanol.
- Geographical variation can have large impacts on energy estimates of the biofuel system. The current estimate of NER of biomass ethanol that utilizes biomass crop production data from Middle Gulf Coast, Edna-Ganado, Texas area is not readily transferable to a more general region.
- Not considered is the issue of form, where the demand for a mobile fuel may justify added costs. The value of having mobile fuels may override many of the impacts described in this study. However, it is important to consider the potential of an alternative fuel not only from an economic perspective but also from an energy perspective. Often times, however, economic approaches are distorted by government intervention through subsidies, tariffs, etc.

4. AGGREGATE ECONOMIC IMPLICATIONS OF NATIONAL GOALS FOR CELLULOSIC BIOFUELS

4.1 Introduction

The United States transportation sector consumed 12 billion gallons of biofuels in 2009 (U.S. Energy Information Administration 2009), mostly in the form of ethanol. With projections suggesting an increase in energy consumption by the U.S. transportation sector and pressures from international communities to restrict food grain use for fuel production, wider ranges of energy sources (feedstocks) are being considered, mainly biomass from agriculture, forestry, and waste materials (U.S. Energy Information Administration 2009).

While the production of biofuels may be politically, and at first thought, economically attractive, several potential issues could prove costly in terms of land use, water use and quality, energy balance, food and animal feed availability, commodity prices, government outlays, and trade balance. With more than 80 percent of the world's food supply comprised of grains, competition between food and fuel crops for land and other resources is expected to translate into higher prices for staple foods globally (Kendall and Pimentel 1994). U.S. prices of major crops and ethanol production during 1980 to 2010 are presented in figure 4-1. Crop prices tend to follow the same trend as ethanol production, suggesting a positive relationship. Similar relationships were found to exist in the evaluation of the impacts of the production of different biofuel mandates

on the economy (Taylor and Lacewell 2009a). However, population is also increasing, suggesting increasing demand for food, further complicating the issue.

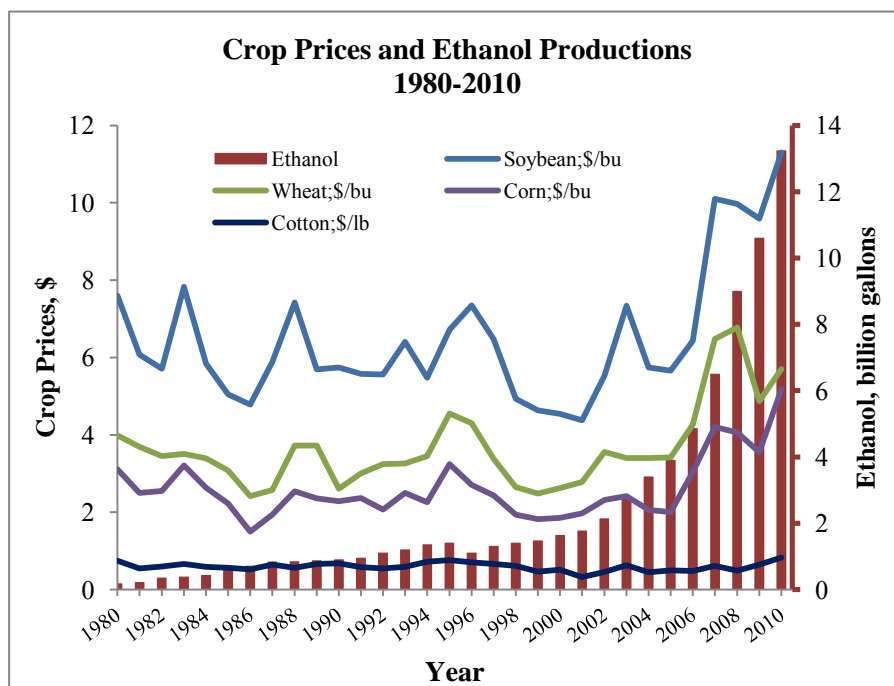


Figure 4-1. Crop prices of major crops and ethanol production in the U.S. during 1980-2010
 Source: Renewable Fuels Association (RFA) 2010b (Ethanol Production), and National Agricultural Statistics Service 2010 (Crop Prices).

A report by the International Assessment of Agricultural Science and Technology for Development (IAASTD) indicates that international increasing populations and income levels will intensify food demand, resulting in competition for land between food and fuel production (IAASTD 2009). Such competition for land could induce crop production on Conservation Reserve Program (CRP) land, which is typically marginal land that is prone to high erosion (i.e., having an erosion index of 8.0 or higher) (Farm Service Agency 2012). This level of an erosion index typically suggests soils highly vulnerable to wind and water erosion under usual row crop

production. Production of feedstock for biofuels on these lands could negate the environmental benefits achieved from the CRP program since its inception.²⁶ However, it is also argued that the addition of CRP land toward crop production could have a dampening influence on prices of food, feed, and forest products, causing a negative impact on farm income, but reducing costs to consumers. Taylor and Lacewell (2009b) found that the addition of CRP land to crop production resulted in decreases in crop prices and consequently increases in consumer surplus by approximately \$5.0 billion annually; however, such gains are accompanied by an expense of 145 million tons in increased annual soil erosion.

Biofuel programs in some countries are supported by government incentives such as blending subsidies, import tariffs, etc. According to the U.S. Department of Agriculture (USDA), biofuel production and its associated incentives have contributed to a 130 percent increase in overall food commodity index between 2002 and 2008 (Trostle 2011). However, incentives are typically justified in the name of achieving broad societal goals, diversifying energy sources, and enhancing energy security. In addition, government assistance and subsidies are enacted to meet environmental objectives, address rising oil prices, promote competition in the global economic market, offset droughts and cyclones, and react to disease and pest outbreaks, all of which otherwise can generate pressures that increase food prices.

This overview of the contemporary environment in which U.S. and international decisions are being executed is suggestive of a need for a comprehensive analysis of the

²⁶ The CRP program was first implemented in 1985 and it is assumed that environmental benefits continue to be realized because of the program.

economic implications of alternative energy policies on agriculture, food, and the environment. Strong support of the biofuels program and potential increases in U.S. acreage dedicated to energy crops warrant an assessment of the expected impacts of production of biomass crops as an energy feedstock and a discussion of the issues surrounding the competition between land use for food, feed, fiber, and fuel purposes. This paper focuses on such an analysis, utilizing an aggregate econometric model of agriculture (Taylor and Taylor 2009) for evaluating the implications of cellulosic feed stock production, alternative energy policies, and government initiatives on agriculture, economic sectors (agriculture, producers, and consumers), and natural resources.

4.2 Objectives

The biofuel policies evaluated in this research are modeled as production mandates compared to a baseline of no mandates and no CRP acres returning to crop production. The scenarios evaluated are designed as specified production levels of cellulosic-based biofuels and a combination of cellulosic and grain-based biofuels. Brief explanations of the biofuel scenarios are presented in table 4-1. The scenarios are implemented and evaluated as the effects of exogenously-specified biofuel mandates fulfilled by the production of a dedicated biomass crop and its consequent effects on commodity prices, fertilizer use and prices, and U.S. society welfare.

Table 4-1. Description Of The Biofuel Production Scenarios Under The Base Case Where No Conservation Reserve Program Land Returns To Crop Production

Scenario^a	Explanation
0+16	Zero billion gallons of grain ethanol and sixteen billion gallons of biomass ethanol.
0+20	Zero billion gallons of grain ethanol and twenty billion gallons of biomass ethanol.
16+16	Sixteen billion gallons of grain ethanol and sixteen billion gallons of biomass ethanol.
16+20	Sixteen billion gallons of grain ethanol and twenty billion gallons of biomass ethanol.

^a The scenarios are developed from the original Renewable Fuel Standard (RFS) mandate. The RFS mandate requires production of 36 billion gallons of renewable fuels by 2022, with 16 billion gallons of grain ethanol and 21 billion gallons of biomass ethanol (Renewable Fuel Association 2010a).

The specific objectives of this study are:

1. Apply a national quantitative model, Agricultural Simulation Model (AGSIM) (Taylor and Taylor 2009), to estimate the impacts of biomass crop production to meet the cellulosic component of the biofuel mandate in addition to the 16 billion gallon grain-based biofuel mandate. The economic impacts estimated include effects on cropping patterns, commodity prices, fertilizer prices, fertilizer use, consumer and producer surplus, and trade balance. The benchmark estimation for comparison purpose is conducted by assuming no expired Conservation Reserve Program (CRP) acres return to crop production.
2. Sensitivity of the economic impacts of production of biofuel mandates are estimated based on alternative assumptions related to expiring CRP grassland acres returning to crop and/or changes in per acre yield of biofuel feedstock production. For CRP grassland acres that are available by region and by year,

25, 50, and 100 percent of the expiring grassland acres are allowed to return to crop production and the associated aggregate economic impacts are estimated.

3. Sensitivity of the aggregate economic impacts of producing the biofuel mandates based on alternative biomass yields of 5.0 and 7.0 dry tons per acre are estimated in comparison to the baseline assumption of 2.69 tons per acre²⁷, the average of SG yield across all U.S. farm resource regions represented in the AGSIM model.

4.3 Review Of Literature

The Energy Independence and Security Act (EISA) of 2007 implemented a RFS, requiring production of 36 billion gallons of renewable fuels by 2022, with 21 billion gallons produced from biomass (Renewable Fuel Association 2010a).²⁸ Although RFS requires a significant portion of the biofuels mandate be derived from the use of cellulosic plant materials, recent production has been below the set target levels. The mandate was set to begin at 100 million gallons in 2010 and rise to 16 billion gallons by 2022. Instead, citing economic and technological hurdles, the Environmental Protection Agency (EPA) reduced this mandate from more than 200 million gallons to 6.5, 6.6, and 8.65 million gallons for 2010, 2011, and 2012, respectively (Environmental Protection Agency 2012). It is uncertain whether the current cellulosic mandate will undergo revision in future years. However, the analyses in this paper assumes that the original cellulosic biofuel mandate of 250 million gallons in 2011 and reaching 16 billion gallons

²⁷ The 2.69 tons/acre SG yield is later adjusted relative to regional hay yields during the estimation of biomass acreage required to meet the cellulosic biofuel demand. The procedure is explained in detail in the Methodology section.

²⁸ At the end of 2010, there was approximately 13 billion gallons of corn-based ethanol being produced (Renewable Fuels Association 2010b).

by 2022 (H.R.6, 110th Congress 2007)²⁹ continues to exist and implementation of such mandate is the basis for the corresponding aggregate economic impacts derived and reported in this study.

According to the Biomass Research Development Initiative (2008), most studies that analyzed the impact of biomass-derived biofuels have examined the use of crop residues, mainly corn stover, for the production of cellulosic-derived biofuels rather than relying on a dedicated biomass crop. Moreover, Marshall and Sugg (2010) reported that several other studies that did analyze the impacts of a dedicated biomass crop to meet the cellulosic part of the biofuel mandate assumed no competition for land with feed grain or other commodity crop production. To produce sufficient biomass to meet the biofuel mandate, it is reasonable to assume competition for cropland between biomass crops and traditional crops, which can impact food and feed prices. To overcome many limitations of past studies, this analysis includes a dedicated biomass crop, Switchgrass (SG), to meet the cellulosic portion of the RFS and provide estimates of the potential consequences of such a production activity on cropping patterns, commodity prices, and producer and consumer surplus.

Fertilizer prices can also be expected to be affected by biofuel production. Taylor and Lacewell (2009a) reported that major plant nutrient prices increased threefold from the baseline due to increased biofuel production. The fertilizer requirement for cellulosic crops is relative to the yield level. Their production on marginal lands plus

²⁹ The cellulosic biofuel mandate increases gradually from 100 million gallons in 2010 to reach 16 billion gallons by year 2022.

higher yields of biomass is expected to result in high fertilizer applications, which in turn influence fertilizer use and price.

Second-generation biofuels production can also influence the price of livestock feed. Cattle feeders experienced a 92 percent increase in cash corn prices between 2006 and 2007 (Young 2008). The change in the price and availability of feed grains can encourage livestock producers to consider alternative dietary regimens. Research shows that livestock and poultry fed on alternative dietary regimens have underperformed compared to their corn-rationed peers (Boyle 2008). However, in the current analysis applying the AGSIM model, livestock supply and demand are not explicitly modeled, but they are implicit in the feed demand equations. Due to lack of livestock inventory data at the regional level, it is a challenge to appropriately separate consumer surplus effects estimated from the feed demand equations (Taylor and Taylor 2009).

Clearly, if the U.S. is to achieve some balance between food, fiber, timber, energy, and the resources needed for a sustainable agriculture, there is a need for evaluation of alternative biofuel policies. The Renewable Fuels Association predicts that U.S. biofuels production by 2022 will only replace 7.0 percent of the nation's expected annual gasoline consumption (Renewable Fuels Association 2010a). This magnitude of potential replacement suggests that large-scale biomass production that can be expected to dramatically contribute to the U.S. energy supply may not be an available alternative to the current use of oil and not even an advisable option for meeting the U.S. energy needs. Although much criticism has been aimed at the U.S. for subsidizing the production of biofuels, the challenge still exists for researchers and policy makers to

develop new conceptual frameworks and institutional arrangements to deal with the various issues on the emerging food, biofuel, and agricultural policy agenda. Interesting relationships could evolve where the response in commodity prices may improve the economic position of agriculture, but harm consumers and the balance of trade.

4.4 Model Description

This analysis of the RFS mandate focuses primarily on application of the AGSIM model, an econometric-simulation model that is based on a large set of statistically-estimated demand and supply equations for major field crops and feed demand in the United States (Taylor and Taylor 2009). AGSIM was initially developed in 1977 to evaluate the economic impacts of using corn, grain sorghum, small grains, and crop residues to convert to ethanol (Taylor 1978). The model has undergone several subsequent revisions and has been used to evaluate several agricultural policies such as expansion of CRP acreage, reduced target prices, tax on nitrogen fertilizer in the U.S., and CRP land returning to production. Application of the model provides insight on expected impacts of alternative policies relative to shifts in cropping patterns, impacts on crop prices, impacts on fertilizer prices and consumption levels, and consumer and producer surplus measures (Taylor et al. 1994; Taylor 1993).

The present version of AGSIM³⁰ model includes supply and utilization of major crops that are regionalized for the nine U.S. Department of Agriculture (USDA) production regions (figure 4-2). The demand for each commodity is separated into imports, exports, livestock feed, food, fiber, ethanol production, other domestic uses,

³⁰ The model description herein is adopted from Taylor and Taylor (2009).

ending stocks, and residual use stocks, all keyed to the USDA annual baseline published in February of each year.

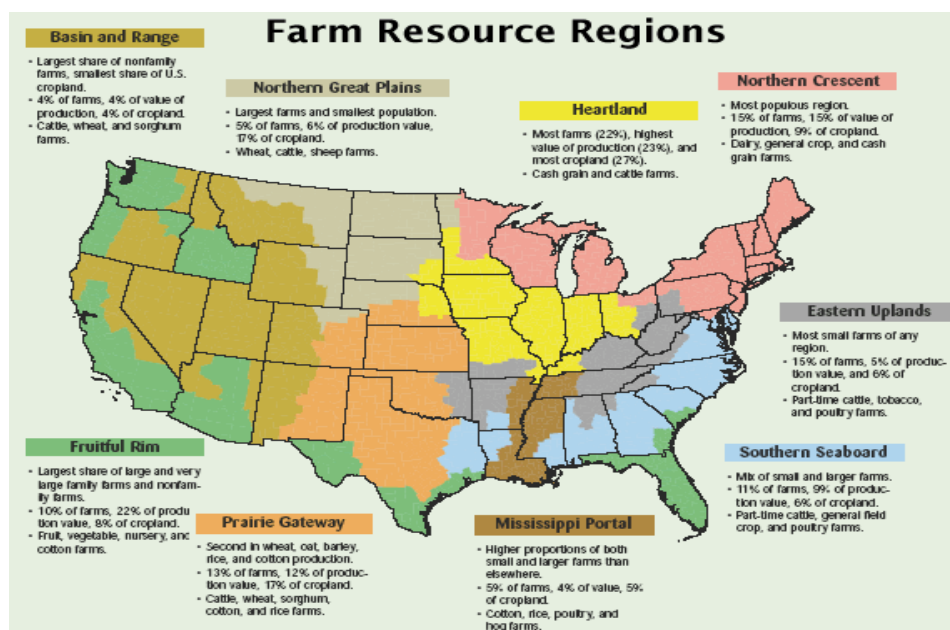


Figure 4-2. U.S. farm resource regions that are keyed to the AGSIM model with the U.S. department of agriculture baseline data from each of the regions, utilized to identify the expected impacts of biofuel production

Source: Economic Research Service (2011a).

The USDA baseline is a report that provides long-run projections for the U.S. agricultural sector, with the most recent baseline providing projections up to year 2020 (Economic Research Service 2011b). Projections cover production and consumption for agricultural commodities, global agricultural trade and U.S. exports, commodity prices, and aggregate indicators of the sector, such as farm income and food prices. This information provides a base for comparison for assessing expected impacts of alternative policies and technologies.

The supply component for each commodity in the AGSIM model is a function of per acre net returns of a crop relative to per acre net returns of other crops. Regional supply is a result of crop acreage adjustments relative to changes in net profitability. For this study, exogenously-specified biofuel policies are incorporated relating to cropland(s) needed for biomass production to meet the RFS specification for cellulosic feedstock. Application of the AGSIM model provides an estimate of a set of prices for all commodities that simultaneously clear all markets in each year, in turn affecting profitability and cropping patterns in subsequent years.

Application of the AGSIM model also provides estimates of the changes in economic welfare based on the concept of economic surplus (Taylor and Taylor 2009), which is calculated as the change in price times the quantity for consumers and change in net farm income for producers. The AGSIM model is designed to provide estimates up to year 2031. To develop forecasts for 2011-31, the AGSIM model is keyed to the USDA baseline that extends for ten years (2011-20). For additional years, i.e., for 2021-31, repeated values from the final year (2020) of the baseline are used. The use of the repeated values from 2021-31 is justified based on the assumption that the U.S. biofuel mandate originally proposed continues to exist and remains at the 16 billion gallon production level through 2031.

The AGSIM model is different from other large-scale agricultural economy models in two ways. First, the AGSIM model uses a single equation to account for total planted acreage in a region, while a set of share equations allocate the total acreage to individual crops in that region. Second, acreage response is based on expected net

returns per acre of crop alternatives rather than unit price, thus allowing for evaluation of policies that could change production costs and yields.

4.5 Methodology

The analysis of cellulosic-based biofuels includes a benchmark analysis. In turn the aggregate economic impacts of different levels of biofuels production (as indicated in table 4-1) are compared against the aggregate economic impacts for a no biofuel scenario baseline. The aggregate economic estimations for the no biofuel scenario baseline and for the four-biofuel production scenarios are initially performed under the assumption of no expired CRP land returning to crop production, i.e., such land remains in pasture or other conserving use.

Switchgrass (SG) is a perennial C4 grass native to North America that is characterized by a high-yielding potential and a tolerance to water and nutrient deficits (McLaughlin, Samson, and Bransby 1996). It is used as a proxy dedicated-biomass crop to represent biomass production. SG was chosen based on the justification provided by Wright (2007), who reported that SG has the following criteria and, hence, is qualified as a biofuel feedstock: (1) noninvasive nature, (2) can be grown on marginal lands, and (3) can be grown with existing equipment and therefore fitting into current farming enterprises.

Sensitivity analyses are conducted to gain insight on the implication of relaxing the CRP assumption, i.e., allowing differing proportions of expired CRP land to return to crop production. In addition, with the apparent discrepancies in reported SG yields across the U.S. and related assumptions potentially influencing the estimated economic

effects, another set of sensitivity analyses with varying biomass yields are conducted to identify the associated changes in the potential economic impacts. Detailed description of the benchmark and the sensitivity analyses are provided in the following subsections.

4.5.1 Benchmark Analysis

This analysis is based on the assumption that cellulosic-based fuels come from a dedicated-biomass crop (SG) and that production will take place on U.S. cropland primarily planted to traditional crops. The basic underlying parameter is that the RFS based on cellulosic fuels will reach 16 billion gallons by 2022³¹. Biofuel policies are exogenously specified by year for the AGSIM model, and associated expected aggregate economic impacts are estimated. As presented in table 4-1, four biofuel production scenarios are considered, each with alternative levels of biofuels mandates initially assumed.

In order to identify the number of acres required to produce the 16 billion gallons of ethanol by 2022, the first step is to estimate the amount of ethanol produced from a ton of biomass, specified as the conversion coefficient (C-C). C-C is a measure of amount of ethanol produced from a unit of biomass (assumed to be on a dry ton basis of less than 15 percent moisture content). The C-C for this analysis is estimated using a simple average approach, i.e., an average of several estimates reported in the literature (table 4-2). The C-C for SG is estimated as 96.5 gallons of ethanol per dry ton of biomass.

³¹ It is recognized that the RFS for biomass-based fuels is being reduced based on updated market assessment and is 8.65 million gallons for 2012 (Environmental Protection Agency 2012). However, as previously noted, the analyses in this study are performed assuming the original cellulosic mandate of 16 billion gallons production by 2022.

Table 4-2. Studies In The Estimation Of The Conversion Coefficient (Gallons Of Ethanol Per Ton Of Switchgrass), Used To Identify The Number Of Acres Of Switchgrass Required To Meet The Biofuel Mandate

Study	Switchgrass to Ethanol Conversion (gallons of ethanol per dry ton of biomass)
Parrish and Fike (2005)	105.6
Morrow, Griffin, and Matthews (2006)	100.3
Farrell et al. (2006)	100.3
Schmer et al. (2008)	100.3
Mitchell, Vogel, and Sarath (2008)	86.8
Felix and Tilley (2009)	71.3
U.S. Department of Energy (2011)	110.9
Average	96.5

A nationwide, uniform, conservative, harvested yield level of 2.69 tons of SG per acre (McLaughlin 2011a) along with the C-C estimated above is used to identify the initial number of biomass acres required to meet the RFS mandate. Hence, to produce 16 billion gallons of ethanol by 2022, a national total of 61.6 million acres of a biomass crop is required.³² As noted earlier, the annual cellulosic mandate proposed in EISA of 2007 is the basis for the cellulosic ethanol production specification in the AGSIM model. The percentage relationship of regional cropland to the total U.S. cropland over the nine regions is used as a criterion to allocate the required biomass acres across the nine U.S. farm resource regions³³. This criterion provides the percentage of biomass

³² To produce 16 billion gallons of ethanol, the number of biomass acres required is estimated by first calculating the gallons of ethanol produced from an acre of biomass, which is biomass yield per acre (2.69) times the number of gallons of ethanol from a ton of biomass (96.5), identified in table 4-2. The biofuel production mandate is then divided by the biofuel production per acre estimated above. Therefore, the number of acres is given by: $16,000,000,000 / (2.69 * 96.5) = 61,606,574$ acres.

³³ Due to lack of data, it is assumed that each region will produce its relative share of biomass.

acreage for each region that is required to reach that region's share of the annual cellulosic ethanol mandate.

There is a lack of data on SG yields for the farm resource regions specified in AGSIM model. Moreover, utilization of a uniform yield level to identify the number of biomass acres for each of the U.S. farm resource regions might either overestimate or underestimate the impact of biomass crop production on crop prices, fertilizer use and prices, and welfare measures. Hence, the hay yield for each region was used as a proxy to define relative switchgrass yield, i.e., the regional biomass acreage initially identified using the uniform harvested yield level of 2.69 tons per acre is adjusted based on relative differences in the hay yields for each of the regions. Presented in table 4-3 are the initial estimates of biomass acres required, regional hay yields, revised SG yields, and the adjusted biomass acreage for each region.

The estimated biomass acreage using the uniform yield of 2.69 ton per acre for Heartland region is 21.74 million acres (table 4-3), i.e., 21.74 million biomass acres were estimated as the requirement in the Heartland region as its regional share to achieve the overall national 16 billion gallon cellulosic biofuel mandate by year 2022. Adjusting the SG yield based on regional difference in hay yield suggests the resulting biomass acreage production in the Heartland region is 19.65 million acres for producing the region's share of the 16 billion gallons of cellulosic biofuels by year 2022. The other regional acreage estimates are interpreted in a similar manner. Since the model is designed to simulate effects until year 2031, once the biomass acres reach the regional target, they are assumed to stay constant from year 2022 until year 2031.

Table 4-3. Initial Biomass Acreage, Hay Yield, Revised Switchgrass Yield, And Adjusted Biomass Acreage For Each Region Estimated Using National Average Switchgrass Yield Required To Reach The Region's Share Of The Cellulosic Mandate Of The Renewable Fuels Standard Under The Assumption Of No Conservation Reserve Program Land Returning To Crop Production

Region ^a	Base SG Yield ^b	Biomass Acreage, under National Average SG Yield	Hay Yield, Tons/acre ^c	Revised SG Yield ^d	Biomass Acreage, Adjusted for the Relative Regional Hay Yield
Heartland	2.69	21,741,185	3.19	2.98	19,651,123
Northern Crescent	2.69	5,449,236	2.99	2.79	5,254,838
Great Plains	2.69	9,582,951	1.94	1.81	14,242,702
Prairie Gateway	2.69	12,096,108	2.83	2.64	12,324,067
Eastern Uplands	2.69	2,632,876	2.50	2.33	3,036,584
Southern Seaboard	2.69	2,702,358	2.71	2.53	2,875,202
Fruitful Rim	2.69	2,431,559	4.92	4.59	1,424,999
Basin and Range	2.69	2,065,499	3.02	2.82	1,972,027
Mississippi Portal	2.69	2,904,801	1.85	1.73	4,527,303
Average^e	2.69		2.88	2.69	
Total		61,606,574			65,308,846

^a Refer to figure 4-2 to locate each region within the U.S.

^b Source: McLaughlin (2011a).

^c USDA Agricultural Projections to 2020 (2011).

^d Revised SG Yield = Base SG Yield *(Regional Hay Yield/National Average Hay Yield); For example, for the Heartland region: $2.69 \times (3.19/2.88) = 2.98$.

^e These are simple averages.

Fertilizer use and price effects of biomass production are an output of the AGSIM model. However, the AGSIM model does not allow incorporating the fertilizer demand relative to the expected yield level of the biomass crops on a regional basis³⁴. Hence, fertilizer requirements corresponding to a yield level of 3.0³⁵ tons per acre are

³⁴ Fertilizer rates per acre for each crop are assumed to be the same for all regions, since data are unavailable for setting required fertilizer use based on crop yield in the AGSIM model.

³⁵ Although 3.0 dry tons per acre yield is considered possible for SG, only an average yield of 2.69 dry tons per acre are realized due to varied planting and harvesting dates, to minimize costs of production (McLaughlin 2011a).

used, an average of adjusted SG yields across all nine U.S. farm resource regions. The Nitrogen (N), Phosphorous (P), and Potassium (K) fertilizers are used in the 3:1:2 proportions, resulting in 60 lb N, 20 lb P, and 40 lb K being applied per acre for SG production in each region.

With ongoing interest in promoting greater use of biofuels, federal programs have been designed to provide significant incentives to biofuel producers in the form of tax credits. Under the Food, Conservation, and Energy Act of 2008, tax credits for corn and soy-based biofuels expired at the end of 2011, whereas tax credits for cellulosic ethanol are set to expire at the end of 2012 (Renewable Fuels Association 2011). However, in estimating the total economic surplus, the tax credit for cellulosic ethanol is assumed to exist through year 2031, providing insights regarding how such an incentive would affect total economic well-being of the society.

Net returns of farmers' are directly impacted through production of feedstocks and indirectly through higher crop and fertilizer prices brought about by resource competition (Ugarte et al. 2007). However, due to the unavailability of national data on SG yields, prices, and other costs, the present version of the AGSIM model does not account for the net farm income associated with the SG production. Hence, the producer surplus estimates only represent the net income associated with the major crop acres.

4.5.2 Sensitivity Analyses – Conservation Reserve Program Acres

The potential return of CRP acres to cropland assuming no additional costs to convert CRP land to cropland is the basis for estimating the relative effects on the production of a biomass crop for energy. Data regarding expiring CRP contracts under

grassland and trees by region and by year are available from the Farm Service Agency (2012) and are included in the AGSIM model. The total cropland and the CRP acreage in each of the U.S. farm resource regions are provided in table 4-4.

Table 4-4. Total Estimated Cropland Acres, Regional Share Of Total Cropland, And Total Conservation Reserve Program Acres In Each Of The Nine U.S. Farm Resource Regions

Region ^a	Total Cropland Acres	Regional Share in Total Cropland	Total CRP Acres
Heartland	124,181,417	35.3%	6,819,014
Northern Crescent	30,955,918	8.8%	1,448,862
Northern Great Plains	53,156,397	15.6%	9,760,225
Prairie Gateway	67,022,192	19.6%	11,084,004
Eastern Uplands	14,802,453	4.3%	362,340
Southern Seaboard	15,263,393	4.4%	1,311,541
Fruitful Rim	13,535,709	3.9%	2,472,071
Basin and Range	11,427,824	3.4%	1,929,222
Mississippi Portal	16,529,681	4.7%	1,583,706
Total	348,602,668	100.0%	36,770,985^b

Source: Taylor and Taylor (2009).

^a See figure 4-2 for location of each region within the U.S.

^b Includes approximately 28 million acres in grassland and 8 million acres in trees.

Several studies surveyed CRP contract holders to identify their plans for CRP lands after contract expiration (Clark 1993; Osborn 1993). These surveys are dated, but the respondents indicate that approximately 50 percent of the current enrollment of CRP acreage is expected to return to crop production across all of the U.S. farm resource regions. The expiring CRP acres are exogenously specified as data for the AGSIM model by region and by year to return to crop production by relaxing the no CRP assumption. A series of sensitivity analyses includes allowing first 25, then 50, and

finally 100 percent of the expiring grassland CRP acreage to return to biomass and/or crop production by region and by year. It is assumed, for the purpose of this analysis, that grassland CRP acreage is relatively simple to convert to crop production compared to CRP acreage under trees. Hence, only expired CRP grassland acres are assumed to return to crop production.

4.5.3 Sensitivity Analyses – Switchgrass Yields

The uniform 2.69 tons per acre harvested SG yield used to estimate initial biomass acreage requirement, and subsequently adjusted using the relative regional hay yields, provides economic consequences that reflect a relatively low yield and high biomass acreage. However, efforts toward developing high-yielding biomass varieties could improve the yield potential (Rooney 2011 in McLaughlin 2011a), resulting in fewer biomass acreage requirements to meet the cellulosic biofuel mandate. Such a decrease in biomass acreage requirements would reduce competition for land with traditional crops, thereby influencing the impacts on crop prices, fertilizer use and prices, and welfare measures. Hence, biomass acreage requirements are re-estimated using SG yields of 5.0 and 7.0 tons per acre that are adjusted by region based on relative differences in regional hay yield.³⁶

4.6 Benchmark Results

The purpose of this research is to provide insight into the aggregate economic effects of production of biofuels to meet the RFS of 36 billion gallons by 2022. The

³⁶The University of Tennessee reported yields of switchgrass grown in test plots primarily for ethanol production to be in the range of 5 to 7 tons per acre (Garland 2008).

effects are measured relative to a zero production level of biofuels. Included in the implications are changes in cropping pattern(s), effects on commodity prices, impacts on fertilizer use and prices, changes in trade balance, and changes in consumer and producer surplus. The biofuel production scenarios evaluated in combination with no CRP assumption and compared against the zero level of biofuels are (1) no grain ethanol and 16 billion gallons of biomass ethanol (0+16), (2) 16 billion gallons of each grain and biomass ethanol (16+16), (3) no grain ethanol and 20 billion gallons of biomass ethanol (0+20), and (4) 16 billion gallons of grain ethanol and 20 billion gallons of biomass ethanol (16+20). The application of AGSIM extends to 2031. There is a solution for each year as the RFS increases to 2022. The results presented herein are for year 2022 after meeting the RFS mandates.

4.6.1 Cropping Pattern Implications

Based on the assumptions of this study, implementation of biomass crop production as a feedstock for energy influences the cropping pattern in all nine of the U.S. farm resource regions. The estimates presented in table 4-5 indicate the national average percentage changes in major crop acres; however, as noted before, the biomass acres required are proportionately allocated across each region, so fewer acres are available for traditional crops in each region.

Table 4-5. Average Percentage Change In Major Crop Acres From Baseline Due To Biofuel Production Mandate Across All Of The U.S. Farm Resource Regions Under Specified Biofuel Scenarios And No Conservation Reserve Program Assumption^a

Scenario	Corn	Soybean	Wheat	Cotton	Hay
Baseline – No Biofuels Production (million acres) ^b	82.6	79.5	52.6	11.6	59.6
-----Percent change from Baseline-----					
0+16 ^c	-14.3	-21.6	-18.4	-12.9	-8.9
16+16 ^d	-5.7	-20.5	-21.3	-12.9	-9.4
0+20 ^e	-17.8	-26.5	-22.8	-15.5	-11.1
16+20 ^f	-7.7	-25.0	-25.9	-15.5	-11.6

^a Assumes CRP acres do not come into crop production and the total U.S. biomass acres required including only major crops to produce 16 and 20 billion gallons of biofuels are 65 and 81 million acres, respectively.

^b Baseline assumes no production of biofuels.

^c No grain ethanol and 16 billion gallon biomass ethanol.

^d 16 billion gallons each of grain and biomass ethanol.

^e No grain ethanol and 20 billion gallons of biomass ethanol.

^f 16 billion gallons of grain ethanol and 20 billion gallons of biomass ethanol.

The total amount of land that can be in production is constrained by the no CRP acres available assumption. As a result, the demand for biomass crop acres results in shifting of acres from major crops in each of the U.S. farm resource regions reported by negative percentage numbers for each of the biofuel production scenarios presented in table 4-5. However, as the demand for grain ethanol is added to the cellulosic ethanol mandate, corn and soybean acres return to production to meet the grain biofuel requirement. As a result, the corn and soybean acres that initially decreased by 14.3 and 21.6 percent, respectively are reduced by only 5.7 and 20.5 percent, respectively, which suggests that 8.6 percent and 1.1 percent of the acres originally under corn and soybean returned to crop production. The return of corn and soybean acres to crop production because of grain ethanol demand and the mandate of cellulosic ethanol results in an

additional decrease in wheat and hay acres. As a result, wheat acres decreased by 21.3 percent under 16+16 compared to 18.4 percent under the 0+16 scenario.

Biomass acres are exogenously specified for each region in the AGSIM model, due to the no CRP acres availability assumption, the resulting biomass acres in each region are forced to come out of the traditional crop production acres. The remainder of the land adjusts across crops. Such a change in crop acres across regions is measured as a percentage change relative to the regional baseline crop acres, represented as the composite change. Table 4-6 presents the baseline acres and composite acreage change in each region. The baseline acres include crop acres under all crops rather than just major crops, as presented in table 4-5.

The estimate of negative 14.4 percent for the Heartland region under the 0+16 biofuel scenario indicates that the crop acres across the region decreased by 14.4 percent from 115.2 million because of production of 16 billion gallons of cellulosic ethanol. The smallest percentage change in crop acres is observed in the Fruitful Rim region, primarily due to low baseline crop acres associated with the region. The overall change across all regions is also presented in table 4-6. The overall change indicates the total change in crop acres under all crops across all regions because of production of biofuel scenarios. The negative 17.1 percent under the 0+16 scenario indicates that the crop acres across all U.S. farm resource regions decreased by 17.3 percent compared to the baseline acres because of production of 0+16 biofuel scenario, mainly due to unavailability of acres due to no CRP assumption. The presence of the grain ethanol mandate in addition to the cellulosic mandate results in returning of acres to crop

production, hence, a relatively smaller percentage decrease in total acres (i.e., a negative 14.3 percent under the 16+16 scenario).

Table 4-6. Baseline Acres And Percentage Changes In Composite Acreage In Each U.S. Farm Resource Region Because Of Production Of The Biofuel Scenarios

Heartland	Northern Crescent	Great Plains	Prairie Gateway	Eastern Uplands	Southern Seaboard	Fruitful Rim	Basin and Range	Mississippi Portal
-----Baseline (No Biofuel Scenario) in Million Acres-----								
115.2	29.0	42.8	55.1	13.8	13.4	10.8	13.0	14.8
-----Percentage Change in Acres from Baseline-----								
Region	0+16 ^a		16+16 ^b		0+20 ^c		16+20 ^d	
Heartland	-14.4%		-11.7%		-17.9%		-14.8%	
Northern Crescent	-15.5%		-13.1%		-19.2%		-16.6%	
Great Plains	-28.8%		-27.0%		-35.9%		-33.9%	
Prairie Gateway	-18.9%		-16.9%		-23.5%		-21.3%	
Eastern Uplands	-9.2%		-3.1%		-11.0%		-4.4%	
Southern Seaboard	-12.7%		-7.4%		-15.2%		-9.4%	
Fruitful Rim	-3.3%		-0.4%		-3.4%		-0.3%	
Basin and Range	-13.9%		-7.0%		-7.9%		-0.5%	
Mississippi Portal	-26.0%		-25.0%		-32.2%		-31.2%	
Total Change Across All Regions	-17.1%		-14.3%		-20.8%		-17.8%	

^a No grain ethanol and 16 billion gallon biomass ethanol.

^b 16 billion gallons of each grain and biomass ethanol.

^c No grain ethanol and 20 billion gallons of biomass ethanol.

^d 16 billion gallons of grain ethanol and 20 billion gallons of biomass ethanol.

4.6.2 Impacts On Crop Prices

Estimated effects of production of cellulosic feedstock for biofuels on major crop prices are presented in table 4-7. As farmers respond to the biofuel mandates, prices and production levels will adjust. Production of biofuels to meet the RFS mandate is expected to increase the average price of the major crops, due to biomass production

replacing the land presently in traditional crops, resulting in cultivation of fewer traditional crop acres. This shift in traditional crop acres causes a reduction in supply of the major crops and an eventual increase in their prices.

Table 4-7. Average Percentage Change In Major Crop Prices From Baseline Prices Due To Biofuel Production Mandate Across All Of The U.S. Farm Resource Regions Under Specified Biofuel Scenarios And No Conservation Reserve Program Assumption^a

Scenario	Corn	Soybean	Wheat	Cotton	Hay
Baseline ^b	\$3.33/bu	\$9.72/bu	\$5.28/bu	\$0.73/lb	\$115.14/ton
-----Percent change in prices from Baseline-----					
0+16 ^c	21.3	11.8	30.3	20.8	17.9
16+16 ^d	41.2	22.7	39.3	20.6	19.2
0+20 ^e	27.9	15.7	39.6	27.7	22.7
16+20 ^f	51.9	28.3	50.0	27.2	24.0

^a Assumes CRP acres do not come into crop production.

^b Baseline assumes no production of biofuels.

^c No grain ethanol and 16 billion gallon biomass ethanol.

^d 16 billion gallons of each grain and biomass ethanol.

^e No grain ethanol and 20 billion gallons of biomass ethanol.

^f 16 billion gallons of grain ethanol and 20 billion gallons of biomass ethanol.

In response to an increase in ethanol demand, corn price increased across all scenarios, with a maximum increase of 51.9 percent under the 16+20 biofuel scenario from the baseline price of \$3.33 per bushel (table 4-7). The increases in soybean prices are, in part, due to demand for soybean for biodiesel and in part, due to demand for corn leading to greater acreage planted to corn acres. As a result, reduced acres are planted to soybean, consequently resulting in an increase in soybean prices.

Although corn and soybean account for more than 90 percent of the ethanol and biodiesel production in U.S., the effect of the RFS mandate is reflected in acres and consequently in the prices of all crops. For example, wheat prices across scenarios

increased in the range of 30.3 to 50.0 percent, the greatest increase compared to other crop prices. The price increases of crops are mainly due to the potential replacement of their acreage by cellulosic feedstock production. It is important to note that such price increases can impact the quantity supplied (i.e., price elasticity of supply); but, the biofuel obligation along with no CRP acres available forces a balance across available land.

4.6.3 Impacts On Fertilizer Use And Prices

With the RFS requiring production of cellulosic feedstock, concerns emerge regarding use of nutrients. On a per acre basis, biomass crops such as SG are described as having relatively low-input requirements (Tilman, Hill, and Lehman 2006), compared to typical crops such as corn.³⁷ The fertilizer requirement for SG, as assumed in this study, portrays a less-fertilizer intensive situation compared to the fertilizer requirement of traditional crops. Biomass production results in cropping pattern shifts such that there are fewer acres in input-intensive crops, resulting in a decrease in total use of primary plant nutrients, in turn causing a decrease in fertilizer prices. However, sensitivity analyses with yield levels for SG of 5.0 and 7.0 tons per acre provides insight relative to the fertilizer implications for the combined effects of higher yield levels of SG and effects of biofuel production mandates.

³⁷ With higher biomass yields, higher fertilizer application rate per acre are required. However, the SG yield level of 2.69 tons per acre (used in the benchmark analysis to estimate the initial biomass acreage) requires relatively less fertilizer per acre compared to other major crops (McLaughlin 2011a).

For the 16+20³⁸ biofuel scenario, nitrogen use decreased by 9.5 percent from a baseline level of 11.6 million tons (table 4-8). Similarly, phosphorous and potassium fertilizer use decreased across all scenarios. The percentage reduction in fertilizer use is not only attributed to the less-fertilizer intensive situation associated with SG crop production, but also to the reduced acres under major crops, which are now replaced with biomass acres. Availability of additional land for crop production by relaxing the assumption of expired CRP land not returning to crop production may have a different impact.

Table 4-8. Average Percentage Change In Fertilizer Use And Price Indices For Nitrogen (N), Phosphorous (P), And Potassium (K) From The Baseline Use And Prices Due To Biofuel Production Mandate Under Specified Biofuel Scenarios And No Conservation Reserve Program Assumption^a

Scenario	N	P	K	N	P	K
	Use, Baseline in Million Tons			Price, Baseline in Dollars/Ton		
Baseline ^b	11.6	5.0	4.9	\$333.10	\$308.20	\$309.10
	-----Percent change from Baseline-----					
0+16 ^c	-11.2	-11.6	-10.8	-9.3	-10.6	-7.4
16+16 ^d	-7.5	-8.1	-7.3	-5.0	-6.7	-4.1
0+20 ^e	-13.7	-14.2	-12.9	-11.1	-12.7	-8.7
16+20 ^f	-9.5	-9.4	-8.0	-6.7	-8.6	-5.3

^a Assumes CRP acres do not come into crop production.

^b Baseline assumes no production of biofuels.

^c No grain ethanol and 16 billion gallon biomass ethanol.

^d 16 billion gallons of each grain and biomass ethanol.

^e No grain ethanol and 20 billion gallons of biomass ethanol.

^f 16 billion gallons of grain ethanol and 20 billion gallons of biomass ethanol.

Fertilizer prices decreased because of reduced fertilizer use associated with SG production, compared to traditional crops such as corn. The presence of a cellulosic

³⁸ 16 billion gallons of grain ethanol and 20 billion gallons of cellulosic ethanol.

mandate and restricting the production on cropland previously under traditional crops through no CRP acres available assumption results in reduced fertilizer demand and consequently a reduction in price.

In producing the 0+16 biofuel scenario, the nitrogen price decreased by 9.3 percent from the baseline level of \$333.10 per ton. The other nutrient prices experienced similar reductions, due to lower overall fertilizer demand. When the grain ethanol mandate is added to the cellulosic mandate, crop acres return to corn and soybean production, resulting in increases in fertilizer demand and eventually fertilizer prices (i.e., 9.3 percent decrease in nitrogen fertilizer price under the 0+16 scenario compared to 5.0 percent decrease in nitrogen price under the 16+16 scenario). Similar trends are observed in other nutrient prices as well.

4.6.4 National Economic Implications

The estimated national economic effects of producing cellulosic feedstock for energy include impacts on net farm income, consumer surplus, taxpayers' expense, and trade balance. It is assumed in the current analysis that the biofuels are produced in addition to the current gasoline supply. The impact of additional supply on the price of the fuel is not captured in the consumer surplus estimation. Due to relatively smaller share of biofuels in the total gasoline consumption of the U.S. (i.e., 36 billion gallons of biofuels account for only 10 percent of total U.S. gasoline consumption), it is assumed to have a minimal effect on the price of the fuel and is thus not accounted for in the consumer surplus estimation. The estimated benchmark analyses impacts, by scenario, under the no CRP assumption are presented in table 4-9.

The production of a cellulosic mandate in the AGSIM model occurs by displacing major crop acres across all U.S. farm resource regions. Due to the reduced supplies of traditional crops, crop prices increase, resulting in an increase of net farm income and a decrease in consumer surplus (i.e., producer surplus increased by \$15.7 billion and consumer surplus decreased by \$7.5 billion under the 0+16 biofuel scenario (table 4-9)). Total economic surplus, which is producer and consumer surplus less combined less any tax credits or subsidies, is negative \$7.9 billion, indicating a net economic loss to the society because of the production of cellulosic biofuels.

Table 4-9. Average Annual Change In Economic Factors From The Baseline Levels Due To Biofuel Production Mandate Under Specified Biofuel Scenarios And No Conservation Reserve Program Assumption^a

Scenario	Net Farm Income (a)	Consumer Surplus (b)	Federal Taxpayer Expense for Biofuel Subsidy ^b (c)	Total Economic Surplus (a + b - c)	Trade Balance
----- \$Billions-----					
Baseline ^c	\$ 65.4	\$ 158.9	\$ -	\$ 224.3	\$ 49.2
----- \$Billion Change from Baseline-----					
0+16 ^d	15.7	-7.5	16.1	-7.9	-2.3
16+16 ^e	43.1	-42.8	16.1	-15.8	-5.5
0+20 ^f	19.9	-17.5	20.2	-17.8	-2.7
16+20 ^g	49.7	-55.9	20.2	-26.4	-5.9

^a Assumes CRP acres do not come into crop production.

^b Assuming subsidy for only cellulosic-based ethanol.

^c Baseline assumes no production of biofuels.

^d No grain ethanol and 16 billion gallon biomass ethanol.

^e 16 billion gallons of each grain and biomass ethanol.

^f No grain ethanol and 20 billion gallons of biomass ethanol.

^g 16 billion gallons of grain ethanol and 20 billion gallons of biomass ethanol.

The addition of the grain ethanol mandate to the cellulosic mandate results in a return returning of corn and soybean acres. With the reduction of corn to ethanol and

biomass production, net farm income increased by \$43.1 billion under the 16 +16 biofuel scenario. Consumer surplus decreased by \$42 billion as a result of increased prices and the total economic surplus decreased by \$15.8 billion under the 16+16 scenario.

These results illustrate how a government mandate for production of a biofuel can have a dramatic impact on producers and consumers. It is these types of unanticipated impacts that need to be considered in evaluating policies to address one issue, such as energy.

Comparing the implications of the 16+20 to the 0+16 scenario in table 4-9, the change in net farm income increased threefold (i.e., an increase from \$15.7 billion to \$49.7 billion) and the change in consumers' negative impact increased almost eightfold (i.e., from a negative \$7.5 billion to a negative \$55.9 billion). These changes indicate that crop prices significantly increased because of production of the RFS mandate. As a result, the change in total economic surplus was reduced by approximately \$18.5 billion and the change in trade balance declined by \$3.6 billion. These results suggest that increases in biofuel production significantly impact the economy and are responsible for a reduction of overall economic surplus.

4.7 Sensitivity Analyses Results

Due to numerous unknowns related to biofuels, including the potential of converting CRP lands back to crop production and conflicting information on SG yields, an expanded set of AGSIM model applications (i.e., sensitivity analyses) are conducted across a wide array of assumptions. The results from these sensitivity analyses provide added insights as to the potential economic impacts of biofuel production.

4.7.1 Conservation Reserve Program Results

Potential pressure increases to grow biofuel feedstocks on marginal lands with the growing demand for food and fuel (Taylor and Lacewell 2009b). Since large amounts of marginal lands that could be used for crop production presently reside in CRP, the aggregate economic impacts of production of biofuels on marginal lands are modeled reflecting the potential availability of CRP land for crop production. Sensitivity analyses are investigated assuming 25, 50, and 100 percent (i.e., 7, 14, and 28 million acres of CRP grasslands) of expiring CRP grassland acres by region and by year returning to crop production. The associated relative changes in economic impacts are compared to the solution for the 16+16 and no CRP biofuel scenario.

4.7.1.1 Impacts On Crop Acres And Prices

Table 4-10 is an overview of the CRP acres returning to cropland and implications for crop acreages, crop prices, and fertilizer prices. In the benchmark 16+16, No CRP scenario, the presence of the cellulosic mandate shifted land away from major crops, increased corn prices, and in turn, affected other grain prices. The availability of additional land through relaxing the no CRP assumption affects the supply-side, resulting in adjustment of acres of the major crops. Application of the AGSIM model allocates cropland based on net profitability and crop acreage shifts are variable for the alternative CRP acres returning to production.

Table 4-10. Average Percentage Change In Crop Acres, Crop Prices, And Fertilizer Prices From 16+16 With No Conservation Reserve Program Land Compared To Conservation Reserve Program Land In Grasslands Returning To Crop Production, Estimated To Identify The Economic Effects Of Additional Land Available For Crop Production During The Production Of Renewable Fuel Standard Mandate

	Crop Acres ^b					Crop Prices ^c					Fertilizer Prices ^d		
	Corn	Soybean	Wheat	Cotton	Hay	Corn \$/bu	Soybean \$/bu	Wheat \$/bu	Cotton \$/lb	Hay \$/ton	N \$/ton	P \$/ton	K \$/ton
16+16; No CRP^a	77.9	63.2	41.4	10.1	54.0	\$ 4.70	\$ 11.90	\$ 7.30	\$ 0.90	\$ 137.20	\$ 316.80	\$ 287.80	\$ 296.50
CRP Acres	-----Percent change from 16+16, No CRP Scenario-----												
7^e	5.8	2.5	3.6	2.0	1.1	-3.2	-1.8	-4.8	-2.5	-2.3	1.2	1.3	0.9
14^e	7.3	5.1	7.2	3.0	2.2	-6.4	-3.6	-9.2	-4.7	-4.5	2.5	2.7	1.8
28^e	10.8	10.4	14.5	6.9	4.4	-12.8	-6.8	-17.0	-8.7	-8.9	5.0	5.5	3.6

^a 16 billion gallon each of grain ethanol and cellulosic ethanol evaluated under no CRP assumption.

^b Crop acres for the scenario 16+16, no CRP are in million acres and the results for the sensitivity analysis of adding CRP acres to cropland are measured as percentage change from the 16+16, no CRP scenario.

^c Crop prices for the scenario 16+16, no CRP are in \$/unit and the results for the sensitivity analysis of adding CRP acres to cropland are measured as percentage change from the 16+16, no CRP scenario.

^d Fertilizer prices for the scenario 16+16, no CRP are in \$/ton and the results for the sensitivity analysis of adding CRP acres to cropland are measured as percentage change from the 16+16, no CRP scenario.

^e Number of CRP acres in million acres returning to crop production, identified in the methodology as 25, 50, and 100 percent of CRP acres in grasslands returning to crop production.

The production of biomass to meet the biofuel mandate in the benchmark analysis resulted in the displacement of relatively more acres previously planted to soybeans and wheat. For the 28 million CRP acres coming back into cropland, wheat acres increased by 14.5 percent, a larger relative amount compared to all other crops. However, for 7 million acres of CRP returning to production, the emphasis is on corn.

Within the operation of the AGSIM model, there are many economic principles, including the response of price to a change in supply, typically referred to as price elasticity of supply. A relatively smaller percentage decrease in crop prices because of the addition of CRP acres to the cropland (table 4-10) suggests that the supply is relatively inelastic. The relatively inelastic supply suggests that change in demand affects crop prices more than supply. Such an effect is evident from the corn price increase by 51.9 percent (table 4-7) for 16+20 scenario in the benchmark analyses compared to the decrease in corn price by only 12.8 percent (table 4-10) for the scenario of addition of 28 million acres of CRP land to crop production.

The addition of 28 million CRP acres (i.e., 100 percent of the CRP grassland acres) decreased corn, soybean, and wheat prices by 12.8, 6.8, and 17.0 percent, respectively (table 4-10). For the decrease in crop price for 7.0 million acres of CRP returning to crop production, by doubling and quadrupling the CRP acres, the price response (decline) is approximately the same (i.e., double and quadruples). The changes in crop prices of other major crops indicate a similar pattern of relatively greater decreases accompanying the addition of greater CRP acres to crop production.

4.7.1.2 Impacts On Fertilizer Prices

Fertilizer application is considered essential for profitable crop production (Tilman, Hill, and Lehman 2002). The addition of CRP grassland to crop acres suggests an increase in consumption of plant nutrients and an eventual increase in fertilizer prices. Nitrogen price increased by 1.2 percent with 7 million CRP acres compared to 5.0 percent with 28 million CRP acres added to cropland (table 4-10). Much the same as crop price changes, the increase in fertilizer prices doubled when CRP acres were doubled and quadrupled for four times increase from 7 to 28.0 million acres.

The relatively-smaller increase in fertilizer prices associated with the addition of 28 million CRP acres (relative to 7 million CRP acres) is attributed to the substantially large acreage requirement by the biomass crops for the purpose of satisfying the RFS mandate, i.e., approximately 65 million acres³⁹ of SG are required to produce sufficient biomass to fulfill the RFS mandate. The addition of 28 million CRP grassland acres to cropland results in a net of 37 million acres of traditional crops being displaced for biomass production. As a result, the addition of 28 million CRP acres results in only a slight increase in fertilizer use and subsequently fertilizer prices.

4.7.1.3 Welfare Impacts

The decrease in crop prices because of the addition of CRP acres to cropland results in a decrease in net farm income. As a result, net farm income decreased by 2.7 percent with the addition of 7 million CRP acres and by 10.4 percent with the addition of

³⁹ Refer to table 4-3 to identify the adjusted biomass acreage requirement to meet the cellulosic biofuel mandate.

28 million CRP acres (table 4-11). The decrease in crop prices resulted in an increase in consumer surplus⁴⁰ of 4.2 percent with the addition of 7 million acres compared to a 15.4 percent increase associated with the addition of 28 million acres (table 4-11). With more land, conventional wisdom suggests that farmers would be better off financially. However, due to price elasticity of demand, the lower commodity prices more than offset the increase in acres, resulting in a lower net income.

Table 4-11. Average Percentage Change In Welfare Effects From 16+16 With No Conservation Reserve Program Land Compared To Conservation Reserve Program Land In Grasslands Returning To Crop Production, Estimated To Identify The Economic Effects Of Additional Land Available For Crop Production During The Production Of Renewable Fuel Standard Mandate

	Net Farm Income	Consumer Surplus	Biofuel Subsidies ^d	Total Economic Surplus	Trade Balance
-----\$ Billions-----					
16+16; No CRP^{a,b}	\$ 108.5	\$ 116.1	\$ 16.1	\$ 208.5	\$ 43.7
CRP Acres	-----Percent Change from 16+16, no CRP Scenario-----				
7^c	-2.7	4.2	-	1.0	0.5
14^c	-5.3	9.4	-	2.5	1.1
28^c	-10.4	15.4	-	3.2	2.5

^a 16 billion gallons each of grain ethanol and cellulosic ethanol evaluated under no CRP as a base assumption.

^b Welfare effects for the scenario 16+16, no CRP are in \$billion and the results for the sensitivity analysis of adding CRP acres to cropland are measured as percentage change from the 16+16, no CRP scenario.

^c Number of CRP acres in million acres returning to crop production, identified in the methodology as 25, 50, and 100 percent of CRP acres in grasslands returning to crop production.

^d Assuming subsidy only for cellulosic ethanol.

The addition of CRP grassland partially offsets the total economic loss by reducing crop prices and increasing consumer surplus. As a result, the total economic

⁴⁰ Recall that the biofuels are produced in addition to the gasoline supply in the U.S. and due to relatively smaller share in total consumption, the impact of additional fuel on the price of fuel is not accounted in the consumer surplus estimation.

surplus increased by 1.0 percent with 7 million additional acres and by 3.2 percent with 28 million additional acres (table 4-11). Accounting for the 3.2 percent increase in total surplus occurring with the addition of 28 million CRP acres, the total economic surplus estimated for the 16+16 and 28 million CRP acres scenario is \$215.1 billion. This surplus estimate is still 4.1 percent lower than the surplus estimated for the no biofuel scenario.⁴¹ This indicates that the addition of 28 million CRP grassland acres to the cropland is insufficient to achieve the well-being/total economic surplus levels associated with the no biofuels scenario and hence supports critics' concern regarding the potential of cellulosic biofuels in achieving economic efficiency in addition to energy security. However, recall that farmer returns to SG are not accounted in the current application of the AGSIM model.

The availability of additional land from CRP results in an increase of production of traditional crops; consequently, domestic supplies of these crops increase along with an increase in net exports. The trade balance, an indicator of net exports, increased 0.5 percent with the addition of 7 million acres up to 2.5 percent with the 28 million CRP acres added to crop production. All of the above economic impacts suggest that competition from biomass production for available land is partially offset by the CRP grassland returning to crop production; however, the CRP land is not sufficient to offset the overall reduction in total economic surplus compared to the no biofuel scenario. Not included in this analysis are the potential environmental impacts of converting marginal

⁴¹ The total surplus for the no biofuel and no CRP is \$224.3 billion; refer to table 4-8 to identify the total surplus under the baseline.

and erosion prone land to crops. Such phenomena represent externalities not quantified herein.

4.7.2 Biomass Yield Results

Developing high-yielding biomass varieties will affect acreage needed to meet the RFS cellulosic biofuel mandate. Sensitivity analyses with 5.0 and 7.0 tons per acre of SG yields combined with the no CRP assumption provide insight into the economic implications. The impacts of higher SG yields can be interpreted similar to the availability of additional land by relaxing the no CRP assumption. Higher biomass yields result in fewer biomass crop acres required to meet the biofuel production mandate, allowing more acres available for traditional crop production and influencing the changes in aggregate economic effects.

4.7.2.1 Impacts On Crop Acres And Prices

The impacts of higher biomass yields and no CRP assumption are compared against the 16+16⁴² and no CRP biofuel scenario. As noted earlier, high-yielding biomass-crops require fewer acres to meet the biofuel demand, thus reducing the requirement of crop acres previously under traditional crops. As a result, land returns to production under traditional crops, evident from the positive percentage changes in crop acres (table 4-12).

⁴² 16 billion gallons each of grain ethanol and cellulosic ethanol.

Table 4-12. Average Percentage Change In Crop Acres, Crop Prices, And Fertilizer Prices From 16+16 With No Conservation Reserve Program Land Compared To Higher Switchgrass Yields, Estimated To Identify The Economic Effects Of Lower Biomass Acre Requirement To Meet The Renewable Fuel Standard Mandate

	Crop Acres ^b					Crop Prices ^c					Fertilizer Prices ^d		
	Corn	Soybean	Wheat	Cotton	Hay	Corn \$/bu	Soybean \$/bu	Wheat \$/bu	Cotton \$/lb	Hay \$/ton	N \$/ton	P \$/ton	K \$/ton
16+16; No CRP^a	77.9	63.2	41.4	10.1	54.0	\$ 4.70	\$ 11.90	\$ 7.30	\$ 0.90	\$ 137.20	\$ 316.80	\$287.80	\$296.50
SG Yield	-----Percent Change from 16+16, no CRP Scenario-----												
5.0^e	10.4	11.4	10.4	6.9	4.4	-10.6	-6.9	-12.1	-8.6	-6.8	4.3	4.8	3.4
7.0^e	12.6	12.3	14.0	8.9	5.9	-14.7	-8.9	-15.6	-11.1	-9.1	5.7	6.7	4.5

^a 16 billion gallon each of grain ethanol and cellulosic ethanol evaluated under no CRP assumption.

^b Crop acres for the scenario 16+16, no CRP are in million acres and the results for the sensitivity analysis for SG yields of 5.0 and 7.0 tons/acre are measured as percentage change from the 16+16, no CRP scenario.

^c Crop prices for the scenario 16+16, no CRP are in \$/unit and the results for the sensitivity analysis for SG yields of 5.0 and 7.0 tons/acre are measured as percentage change from the 16+16, no CRP scenario.

^d Fertilizer prices for the scenario 16+16, no CRP are in \$/unit and the results for the sensitivity analysis for SG yields of 5.0 and 7.0 tons/ acre are measured as percentage change from the 16+16, no CRP scenario.

^e SG yield levels in tons/acre with no CRP acres.

The additional acres available due to reduced competition from the biomass acres primarily go to wheat, soybean, and corn production, where the respective acreages increased by 14.0, 12.3, and 12.6 percent, respectively, under the SG yield level of 7.0 tons per acre. Recall that the AGSIM model allocates total cropland based on net profitability.

The availability of high-yielding biomass crops is evaluated as an increase (shift) in supply with biofuel demand held constant. The additional acreage available through reduced competition from biomass acres shifts the supply curve of the crops to the right, thus resulting in decreases in crop prices. The results presented in table 4-12 indicate that for 7.0 tons per acre SG yields, corn and wheat prices decreased by 14.7 and 15.6 percent, greater percentages compared to other crops. A similar trend of decreasing crop prices is observed across all other major crops; however, by a relatively lower percent compared to wheat and corn.

4.7.2.2 Impacts On Fertilizer Prices

Fertilizer prices increase under higher biomass yield scenarios because of the greater fertilizer demands associated with increasing crop acreages of major crops. Nitrogen price increased by 4.3 percent and 5.7 percent for 5.0 tons per acre and 7.0 tons per acre SG yield, respectively (table 4-12). Due to higher SG yields, fewer biomass acres are required to produce the biofuel mandate; as a result, more acres are available for traditional crop production⁴³ as well as more fertilizer is required on the SG acres due

⁴³ The fertilizer requirement for SG in the current analysis portrays a less fertilizer-intensive situation, as the fertilizer requirement is relative to the SG yield levels. However, higher SG yields demand high fertilizer use per acre.

to the greater yield. Since traditional crops are relatively-more fertilizer intensive compared to biomass crops, fertilizer demand increases and eventually so do fertilizer prices.

4.7.2.3 Welfare Impacts

Welfare effects indicate that farm income decreases due to greater crop output, i.e., due to the price elasticity of demand, the lower commodity prices offset the increase in supply, resulting in lower net income. Fewer biomass acres due to higher production potential of SG crops and an eventual increase in traditional crop acres increase the supplies of major crops, resulting in decreases of major crop prices and an eventual increase in consumer surplus. The net farm income decreased by 10.4 and 13.6 percent for the 5.0 and 7.0 tons per acre SG yield, respectively (table 4-13). Moreover, due to greater crop output and an eventual decrease in commodity prices, consumer surplus increased by 11.1 and 15.4 percent for 5.0 and 7.0 tons per acre SG yields, respectively.⁴⁴

Total surplus that accounts for the net farm income, consumer surplus, and biofuel tax credits indicates an increase of 0.8 and 1.5 percent for 5.0 and 7.0 tons per acre SG yield, respectively (table 4-13). Accounting for the 1.5 percent increase in total surplus for a SG yield of 7.0 tons per acre, the production of 16+16 and no CRP biofuel scenario results in a total economic surplus of \$211.6 billion. This surplus is still 5.6

⁴⁴ The additional acres available due to reduced competition from the biomass acres primarily go to wheat, soybean, and corn production, where the respective acreages increased by 14.0, 12.3, and 12.6 percent, respectively, under the SG yield level of 7.0 tons per acre. Recall that the AGSIM model allocates total cropland based on net profitability.

percent lower than the surplus estimated for the no biofuel scenario.⁴⁵ Therefore, biomass yields 5.0 and 7.0 tons per acre are insufficient to achieve the total economic surplus levels similar to pre-biofuel producing levels, renewing concerns about the potential of cellulosic biofuels to contribute to energy security. Again, a limitation of this analysis is that any returns to SG are not captured.

Table 4-13. Average Percentage Change In Welfare Effects From 16+16 With No Conservation Reserve Program Land Compared To Higher Switchgrass Yields, Estimated To Identify The Economic Effects Of Lower Biomass Acre Requirement To Meet The Renewable Fuel Standard Mandate

	Net Farm Income	Consumer Surplus	Biofuel Subsidies ^c	Total Surplus	Trade Balance
-----\$ Billions-----					
16+16; No CRP^a	\$ 108.5	\$ 116.1	\$ 16.1	\$ 208.5	\$ 43.7
-----Percent Change from 16+16, No CRP Scenario-----					
SG Yield					
5.0^b	-10.4	11.1	-	0.8	2.1
7.0^b	-13.6	15.4	-	1.5	3.0

^a 16 billion gallon each of grain ethanol and cellulosic ethanol evaluated under no CRP assumption.

^b SG yield levels in tons/acre.

^c Assuming subsidy for only the cellulosic based ethanol.

The trade balance is estimated to increase due to the increase in domestic supplies of the major crops. The trade balance increased by 3.0 percent for 7.0 tons per acre SG yields (table 4-13). Higher SG yields results in a lower biomass acreage requirement to achieve the RFS, allowing more acres for traditional crop production. Consequently, there is an increase in the production of traditional crops and an opportunity for greater exports, resulting in an increase in trade balance.

⁴⁵ The total surplus for the no biofuel and no CRP is \$224.3 billion; refer to table 4-8 to identify the total surplus under the baseline.

The results for the biomass-yield sensitivity analyses suggest that availability of higher-yielding biomass crops would cause a minimal decrease in crop prices, but would result in a reduction of total economic surplus compared to the no biofuel mandate analysis. The sensitivity analyses results imply that even with the availability of higher-yielding biomass crops and use of CRP land, production of biofuel mandates results in economy-wide negative implications. These results will help policy makers and the public understand the economic consequences associated with a bioenergy policy even with potential of added cropland and greater per acre biomass yields.

4.8 Conclusion

This study provides insights into the possible domestic and international economic impacts potentially resulting from the U.S. cellulosic biofuel mandates reflected in the RFS. Cellulosic ethanol through biomass crop production was integrated into the grain ethanol mandate using four-biofuel scenarios, namely 0+16, 16+16, 0+20, and 16+20.⁴⁶ These four-biofuel production mandates considered in addition to the assumption of no CRP acres returning to crop production to evaluate the U.S. economy-wide implications of U.S. bioenergy policy that are compared against the economic impacts of a no biofuels scenario. A dedicated cellulosic feedstock production was assumed to compete for agricultural cropland, affecting the production of conventional grain and other crops. Also considered was the potential of additional land currently under CRP returning to crop production and reducing competition with

⁴⁶ The first term indicates the grain ethanol mandate and the second term indicates the cellulosic ethanol mandate.

existing cropland. For all cases, SG serves as a proxy for the cellulosic feedstock to meet the RFS.

Crop price increases that are expected as a result of the biofuel mandate are substantial across all scenarios. Major plant nutrient use and price levels decreased by small percentages compared to the baseline scenario, which is the no biofuels scenario. The aggregate economic effects also indicate a significant negative economic surplus due to a decrease in consumer surplus resulting from high commodity prices. The trade balance, a measure of net exports, decreased compared to the baseline conditions due to reduced supplies of major crops and increased domestic demand from the biofuel sector. The results from the current analysis add to conclusions of Taylor and Lacewell (2009a), who reported that crop prices, fertilizer prices and total economic surplus decrease because of production of first-generation biofuels. The current analysis that evaluates the aggregate economic effects of production of first and second-generation biofuels identified a similar effect, i.e., increases in crop and fertilizer prices and a decrease in total welfare, suggesting need for a careful reevaluation of the U.S. energy policy with close attention to aggregate economic impacts.

All of the above results suggest that the present biofuel policies are associated with large costs to consumers in terms of increased commodity prices and tax burden to support the biofuel incentive. Alternatively, the beneficiaries are the agricultural producers where producers' net income is projected to increase. However, it is crucial to recall that the net income associated with SG production is not accounted for in the estimation of the welfare impacts. Availability of data on SG yields and associated

prices would improve the current version of the AGSIM model, suggesting that there are values not captured, including farmers' net returns for SG production and potential reduction in mobile fuel prices for all consumers.

Sensitivity analyses assuming CRP grassland acres returning to crop production identify interesting insights on aggregate economic implications. The results from the sensitivity analyses indicate that the net economic surplus decreased by 4.1 percent compared to the no biofuels scenario, which is primarily attributed to a decrease in consumer surplus through increased crop prices. These results are contrary to Tonya Vinas of Lean and Green News claim, *“Cellulosic ethanol is more economically and environmentally sustainable because it is not tied to price-sensitive food crops such as corn and soybeans.”*

Higher biomass yields result in fewer biomass acres required to meet the cellulosic mandate. This results in an increase in availability of acres for traditional crops, a similar intuition of having additional land by allowing CRP grassland to return to crop production. The evaluation of aggregate economic impacts using higher biomass yields produced decreases in expected crop prices, increases in fertilizer prices, a decrease in net farm income, an increase in consumer surplus, an increase in total surplus, and increase in trade balance. The sensitivity analyses of high biomass yield results indicate that the net economic surplus decreased by 5.6 percent compared to the no biofuels scenario, supporting claims of Taylor and Lacewell (2009a) that dedicated bioenergy crops compete with food crops for land and other production inputs, thereby impacting food and input prices. In addition, there are potential environmental impacts

of production of dedicated biomass crops on marginal lands, which are not incorporated into the total surplus estimation.

While the production of biomass for ethanol is touted as a future energy solution, there are unexpected consequences of bioenergy policy that are often ignored. The results presented in this paper represent a robust set of expected shifts and economic impacts, suggesting a need for policy makers to be deliberate before acting and warrant their identifying and considering multiple alternative energy sources to achieve a sustainable energy goal. Reductions in consumer surplus evolve due to price increases for commodities. These price increases can be expected to impact lower income society more severely than others through higher food prices. Thus, there is a need to identify and consider those sectors most impacted by energy and other policy decisions.

4.9 Limitations

The results of this study are obviously influenced by a number of factors and assumptions, but they also provide significant insights into the impact of cellulosic biofuels on the economy. Some of the limitations of this study are important to consider for further improving the analysis. The limitations include:

- It is assumed that the biomass is a dedicated cellulosic crop and that it competes directly with existing cropland, while there are other sources of cellulosic feedstocks such as timber and hay that could be considered.
- Fertilizer requirements for the biomass crop considered in the analysis are not expressed on a regional yield basis, but instead are modeled on a national basis. Moreover, fertilizer use is relative to the biomass crop yields. Higher yield levels

require higher applications that can affect both fertilizer prices and overall welfare.

- The data on biomass crops relative to conversion to fuel are premature. A consistent, science-based estimate on specific biomass types conversion coefficients would be useful in providing better estimates of the aggregate welfare impacts.
- The model does not capture the effect of future developments or technology change in the U.S and in the rest of the world that could affect the U.S food sector.
- The current analysis does not explicitly model livestock supply and demand, primarily due to lack of livestock inventory data at the regional level. Although the demand and supply equations of livestock are implicit in the feed demand equations, it is a challenge to appropriately separate consumer surplus effects.
- Net farm income associated with the biomass production is not accounted in the economic impacts estimation, mainly due to unavailability of data on national SG yields, prices, and costs. Availability of such data would help to identify a better estimate of the total economic surplus implications.
- Externalities related to impacts on natural resources such as irrigation use, water quality, and soil erosion because of production on marginal lands, etc are not included.
- Net energy balances associated with the different scenarios are not calculated, but it is important to have insight on energy in versus energy out. Such a

physical measure is frequently reported in literature. Although such a standard is lacking in providing a comprehensive overall net value of alternative scenarios compared to economic assessments, inclusion of energy balance statistics would provide for identifying a relatively comprehensive conclusion.

- Extending the prior limitation, the value of having mobile fuels may override many of the impacts described in this study. The issues of form and place are not considered. However, it is important to consider the potential of an alternative fuel not only from an energy perspective, but also from an economic perspective. Often times, however, economic approaches are distorted by government intervention through subsidies, tariffs, etc. Potential benefits of an increase in mobile fuels with a lower per gallon price were not included in the analysis, but are deemed worthy of being included in future research.

5. SUMMARY AND IMPLICATIONS FOR FUTURE RESEARCH

There are several prior studies related to economic implications of corn ethanol for fuel. This analysis takes a dramatically-detailed view of the environmental, economic, energy return implications of cellulosic-based biofuels. The misconceptions of cellulosic based fuels as a panacea to the growing energy demand for the nation are clearly exposed in this dissertation. In addition, several interesting insights were recognized while developing the models, interpreting the analyses, identifying the limitations, challenges, and needs for future research.

There are unintended consequences of biofuel crop production. Potential water quality damages can result from production of biomass crops. Management options to mitigate such damages involve substantial investment and operation costs that contribute to the cost of ethanol as much by as much as \$ 0.51 per gallon, in addition to the biomass crop production costs that are in the range of \$2.12 per gallon of ethanol. These additional costs suggest that the U.S. needs to assess the broader environmental issues, of biofuels not limited to only the increase of fuel supply to the economy.

Evaluation of the efficiency of various cellulosic crops produced on a pilot level to supply feedstocks to a 30 million gallon ethanol facility resulted in a positive energy balance. However, due to a significant amount of energy embedded in the crop production inputs, the additional cost to produce ethanol increased in the range of \$2.70 to \$3.37 per gallon. These additional costs suggest that the goal of renewable energy

policy must not just increase the supply of biofuels but account for the net energy of biofuels production and its consequent impact on the cost per gallon of fuel.

Finally, dedicated biomass crops are expected to compete for existing cropland and can result in substantial increases in crop prices. Although producers are significant beneficiaries of higher crop prices, the society is the loser due to higher cost of agriculture-based products. All of the above assessments suggest that biofuels at present are still far from being a sustainable option to contribute to the energy demand of the country.

Throughout this dissertation, an attempt to accurately account for the major factors that affect the estimates of economic costs of biomass crop production was undertaken. In some cases, either data limitations or methodological complexities resulted in providing a less than comprehensive economic estimates that might be addressed through additional research. A summary of important areas for new research, which, if carried out, have the potential to increase accuracy of future assessments.

- Society may not benefit from stringent water protection goals. Although all the benefits from water quality protection are difficult to measure, information on such benefits is essential to develop optimal water quality protection levels.
- Secondary energy inputs (i.e., energy used in manufacturing of machinery, vehicles, etc.) are not accounted for in this research. Such energy estimates are useful in estimating a comprehensive energy return estimates of biomass crops.

- In AGSIM, the biofuels produced from both cellulosic and grain crops are not accounted for in evaluating the impact of additional fuel on the price of the fuel and the consequent impact on consumer surplus due to reduced fuel prices. This research can potentially be extended to account for such economic impacts.

REFERENCES

- Adusumilli, N.C., R.D. Lacewell, C.R. Taylor, and M.E. Rister. 2010. "Aggregate Economic Impacts of National Bioenergy Policy-A Review." Accessed December 2011. Available at: <https://sites.auburn.edu/academic/ag/group/bioenergy/>.
- Akobundu, E., and D. W. Riggs. 2000. "Pervasive Permitting: The EPA's Proposed TMDL Rules." *Water Resource Impact* 2(3): 4-6.
- Arnold, J.G., R. Srinivasan, R.S. Muttiah, and J.R. Williams. 1998. "Large Area Hydrologic Modeling and Assessment Part I: Model Development." *Journal of American Water Resources Association* 34(1): 73-89.
- Arrow, K.J. 1969. "The Organization of Economic Activity: Issues Pertinent to the Choice of Market Versus Nonmarket Allocation." *The Analysis and Evaluation of Public Expenditure: The PPB System* 1: 59-73.
- Asheim, G.B. 1994. "Net National Product as an Indicator of Sustainability." *Scandinavian Journal of Economics* 96: 257-265.
- Basset, N., M. Kermah, D. Rinaldi, and F. Scudellaro. 2010. "The Net Energy of Biofuels." Accessed February 2012. Available at <http://www.iperasmuseprobio.unifg.it>.
- Biomass Research and Development Initiative. 2008. "Increasing Feedstock Production for Biofuel: Economic Drivers, Environmental Implications, and the Role of Research." Accessed August 2011. Available at http://www.usbiomassboard.gov/pdfs/increasing_feedstock_revised.pdf.

- Blottnitz, V.H., and M.A. Curran. 2007. "A Review of Assessments Conducted on Bio-Ethanol as a Transportation Fuel from a Net Energy, Greenhouse Gas, and Environmental Life Cycle Perspective." *Journal of Cleaner Production* 15: 607-619.
- Blumenthal, J.M. 2011. Former Extension Agronomist with Texas AgriLife. Texas AgriLife Extension Service, Texas A&M University, College Station, TX. Personal Communication. March 10, 2011.
- Bonari, E., M. Mazzoncini, A. Peruzzi, N. Silvestri. 1992. "Evaluations of the Energy Systems at Different Intensification Agricultural Levels." *The Agrarian Informer* 1: 11-25.
- Boyle, J.P. 2008. *Energy Market Effects of the Renewable Fuel Standard*. Testimony of J. Patrick Boyle of American Meat Institute to the Senate Energy and Natural Resources Committee. American Meat Institute. Washington, DC.
- Bracmort, K., R. Schenf, M. Stubbs, and B.D. Yacobucci. 2010. *Cellulosic Biofuels: Analysis of Policy Issues for Congress*. Washington, DC: Congressional Research Service Report, RL34738, September.
- Clark, T.R. 1993. "Expected Effectiveness of Future Conservation Reserve Program Strategies." *Proceedings of the Great Plains Agricultural Council* 1: 134-149.
- Di Luzio, M., R. Srinivasan, and J.G. Arnold. 2004. "A GIS-Coupled Hydrological Model System for the Watershed Assessment of Agricultural Nonpoint and Point Sources of Pollution." *Transactions in Geographic Information Systems* 8 (1): 113-136.

- Economic Research Service. 1994. *Agricultural Resources and Environmental Indicators*. Washington, DC: U.S. Department of Agriculture Report, Agricultural Handbook No. 705, January.
- _____. 2011a. "Agricultural Resource Management Survey (ARMS): Resource Regions." Accessed August 2011. Available at <http://www.ers.usda.gov/briefing/arms/resourceregiions>.
- _____. 2011b. "U.S. Department of Agriculture Agricultural Projections to 2020." Accessed August 2011. Available at <http://www.ers.usda.gov/publications/ocel11/>.
- Energy Information Administration. 2009. "How can we Compare or Add up our Energy Consumption?" Accessed February 2012. Available at http://www.greatlakesenergyservice.org/documents/comparing_energy_consumption.pdf.
- _____. 2012. "Ethanol." Accessed February 2012. Available at <http://www.eia.gov/oiaf/ethanol3.html>.
- Environmental Protection Agency. 2012. "Regulation of Fuels and Fuel Additives: 2012 Renewable Fuel Standards." *Federal Register* 77(5): 1320-1357.
- Falconer, L.M. 2010. Texas AgriLife Extension Economist, District 11, Corpus Christi, TX. Personal Communication. September 28, 2010.
- Farm Service Agency. 2012. "Conservation Programs: Conservative Reserve Program." Accessed January 2012. Available at <http://www.fsa.usda.gov/FSA/webapp?area=home&subject=copr&topic=crp>.

- Farrell, A.E., R.J. Pelvin, B.T. Turner, A.D. Jones, M. O'Hare, and D.M. Kammen. 2006. "Ethanol Can Contribute to Energy and Environmental Goals." *Science* 311(5760): 506-508.
- Felix, E., and D.R. Tilley. 2009. "Integrated Energy, Environmental, and Financial Analysis of Ethanol Production from Cellulosic Switchgrass." *Energy* 34(4): 410-436.
- Fulton, L., T. Howes, and J. Hardy. 2004. "Biofuels for Transport: An International Perspective." International Energy Agency, Paris, France. Accessed June 2011. Available at <http://www.iea.org/textbase/nppdf/free/2004/biofuels2004.pdf>,
- Garland, C.D. 2008. *Growing and Harvesting Switchgrass for Ethanol Production in Tennessee*. Knoxville, TN: The University of Tennessee Extension Report, Report No. SP701A-5M-5/08, January.
- Gascho, G.J., R.D. Wauchope, J.G. Davis, C.C. Truman, C.C. Dowler, J.E. Hook, H.R. Sumner, and A.W. Johnson. 1998. "Nitrate-Nitrogen, Soluble, and Bioavailable Phosphorus Runoff from Simulated Rainfall after Fertilizer Application." *Soil Science Society of America Journal* 62: 1711-1718.
- Gellings, C.W., and K.E. Parmenter. 2004. "Energy Efficiency in Fertilizer Production and Use." In C.W. Gellings, and K. Blok, eds. *Efficient Use and Conservation of Energy*. Oxford UK: EOLSS Publishers, pp. 1-15.
- Graboski, M.S. 2002. *Fossil Energy Use in the Manufacture of Corn Ethanol*. Chesterfield, MO: National Corn Growers Association, Unnumbered Report, January.

- Green, M.B. 1987. "Energy in Pesticide Manufacture, Distribution and Use." In B.A. Stout and M.S. Mudahar, eds. *Energy in Plant Nutrition and Pest Control* Amsterdam: Elsevier, pp. 165-177.
- Griffin, R.C. 2006. *Water Resource Economics – The Analysis of Scarcity, Policies and Projects*. Cambridge: MIT Press.
- Grismer, M.E., A.T. O'Geen, and D. Lewis. 2006. *Vegetative Filter Strips for Nonpoint Source Pollution Control in Agriculture*. Davis, CA: University of California Agriculture and Natural Resource Publication 8195, January.
- H.R. 6 - 110th Congress. 2007. "Energy Independence and Security Act of 2007." . Accessed December 2011. Available at <http://www.gpo.gov/fdsys/pkg/BILLS-110hr6enr/pdf/BILLS-110hr6enr.pdf>
- Helmers, M.J., T.M. Isenhardt, M.G. Dosskey, S.M. Dabney, and J.S. Strock. 2008. *Buffers and Vegetative Filter Strips*. Chapter 4 in Upper Mississippi River Sub-basin Hypoxia Nutrient Committee. St. Joseph, MI: American Society of Agricultural and Biological Engineers Report: Gulf Hypoxia and Local Water Quality Concerns Workshop.
- Heslop, L.C., and W.K. Bilanski. 1989. *Productive Worth of Different Tillage Machinery across Soil Types*. St. Joseph, MI: American Society of Agricultural Engineers Paper No. 89-1615.
- Hill, J., E. Nelson, D. Tilman, S. Polasky, and D. Tiffany. 2006. "Environmental, Economic, and Energetic Costs and Benefits of Biodiesel and Ethanol Biofuels." *Proceedings of National Academy of Sciences* 103(30): 11206-11210.

International Assessment of Agricultural Science and Technology for Development

- (IAASTD). 2009. *Agriculture at a Crossroads: Syntheses Report*. Washington, DC: Unnumbered Report, January.
- Kendall, H.W., and D. Pimentel. 1994. "Constraints on the Expansion of the Global Food Supply." *Ambio* 23(3): 198-205.
- Lal, R., and B.A. Stewart. 1995. *Soil Processes and Water Quality*. Catalog Number L980. CRC Press, USA.
- Lal, R., and D. Pimentel. 2007. "Biofuels from Crop Residues." *Soil & Tillage Research* 93: 237-238.
- Lee, T., M.E. Rister, B. Narashimhan, R. Srinivasan, D. Andrew, and M.R. Ernst. 2010. "Evaluation and Spatially Distributed Analyses of Proposed Cost-Effective BMPs for Reducing Phosphorous Level in Cedar Creek Reservoir, Texas." *American Society of Agricultural and Biological Engineers* 53(5): 1619-1627.
- Lee, T., R. Srinivasan, J. Moon, and N. Omani. 2011a. "Estimation of Fresh Water Inflow to Bays from Gauged and Ungauged Watersheds." *Applied Engineering in Agriculture* 27(6): 917-923.
- Lee, T., B. Narasimhan, and R. Srinivasan. 2011b. *Eagle Mountain Watershed: Calibration, Validation, and Best Management*. College Station, TX: Texas Water Resources Institute, Technical Report No 408, January.
- Logan, T.J. 1993. "Agricultural Best Management Practices for Water Pollution Control: Current Issues." *Agriculture, Ecosystems & Environment* 46(1): 223-231.

- Lorenz, D., and D. Morris. 1995. *How Much Energy Does it Take to Make a Gallon of Ethanol?* Washington, DC: Institute for Local Self-Reliance, Unnumbered Report, February.
- Malcolm, S.A., M.P. Aillery, and M. Weinberg. 2009. "Ethanol and a Changing Agricultural Landscape." Washington, DC: U.S. Department of Agriculture, Economic Research Service, Economic Research Report 86, June.
- Marshall, L., and Z. Sugg. 2010. *Fields of Fuel: Market and Environmental Implications of Switching to Grass for U.S. Transport.* Washington, DC: World Resources Institute, World Resources Institute Policy Note No. 5, January.
- Martinez, J., and G. Guiraud. 1990. "A Lysimeter Study of the Effects of a Ryegrass Catch Crop during Wheat/Maize Rotation on Leaching and on the Following Crop." *Journal of Soil Science* 41: 5-16.
- MathPro Inc. 2005. "The Net Energy Value Of Corn Ethanol: Is It Positive Or Negative?" Accessed April 2012. Available at <http://www.mathproinc.com/pdf/>.
- McCracken, D. V., M.S. Smith, J.H. Grove, C.T. MacKown, and R.L. Blevins. 1994. "Nitrate Leaching as Influenced by Cover Cropping and Nitrogen Source." *Soil Science Society of America Journal* 58(5): 1476-1483.
- McLaughlin, S.B., R. Samson, and D. Bransby. 1996. "Evaluating Physical, Chemical, and Energetic Properties of Perennial Grasses as Biofuels." *Proceeding of the 7th National Bioenergy Conference*, Nashville.

- McLaughlin, S.B., and M.E. Walsh. 1998. "Evaluating Environmental Consequences of Producing Herbaceous Crops for Bioenergy." *Biomass Bioenergy* 14: 317-324.
- McLaughlin, W.A. 2011a. "The Economic and Financial Implications of Supplying a Bioenergy Conversion Facility with Cellulosic Biomass Feedstocks." Master of Science Thesis, Department of Agricultural Economics, Texas A&M University, College Station, TX.
- _____. 2011b. Former Graduate Student in Department of Agricultural Economics. Texas A&M University, College Station, TX. Personal Communications. March 10, 2011.
- Miranowski, J.A. 2004. "Energy Consumption in U.S. Agriculture." Presentation at USDA Conference on Agriculture as a Producer and Consumer of Energy. Accessed February 2012. Available at [http://www.farmfoundation.org/projects/03-35Energy Conference Presentations.html](http://www.farmfoundation.org/projects/03-35Energy%20Conference%20Presentations.html).
- Mitchell, R., K.P. Vogel, and G. Sarath. 2008. "Managing and Enhancing Switchgrass as a Bioenergy Feedstock." *Biofuels, Bioproducts, and Biorefining* 2: 530-539.
- Morrow, W.R., W.M. Griffin, and H.S. Matthews. 2006. "Modeling Switchgrass Derived Cellulosic Ethanol distribution in the United States." *Environmental Science and Technology* 40(9): 2877-2886.
- National Agricultural Statistics Service. 2010. "Agricultural Prices." Accessed August 2011. Available at <http://quickstats.nass.usda.gov/>.
- National Renewable Energy Laboratory. 2007. "Cellulosic Ethanol." Accessed December 2011. Available at <http://www.nrel.gov/biomass/pdfs/40742.pdf/>.

- Natural Resources Conservation Service. 2010. "National Conservation Practice Standards-NHCP." Code 393. Accessed May 2011. Available at http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs143_025825.pdf.
- Office of Management and Budget. 2010. "Table of Past Years Discount Rates, Appendix C." Washington, DC: Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs, OMB Circular No. A-94, June.
- Osborn , C.T. 1993. "The Conservation Reserve Program: Status, Future, and Policy Options." *Journal of Soil and Water Conservation* 48(4): 271-278.
- Parrish D.J., and J.H. Fike. 2005. "The Biology and Agronomy of Switchgrass for Biofuels." *Critical Reviews in Plant Science* 24(5): 423-459.
- Patty, L., B. Real, and J.J. Gril. 1997. "The Use of Grassed Buffer Strips to Remove Pesticide, Nitrate, and Soluble Phosphorous Compounds from Runoff Water." *Pesticide Science* 49: 243-251.
- Perlack, R.D., L.L. Wright, A.F. Turhollow, R.L. Graham, B.J. Stokes, and D.C. Erbach. 2005. "Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion Ton Annual Supply." *Environmental Science and Technology* 40: 1744-1750.
- Pimentel, D. 2001. *Biomass Utilization, Limits of*. Ed. R.A. Meyers. Encyclopedia of Physical Science and Technology, Vol. 2, 3rd Edition. San Diego, CA: Academic Press, pp.159-171.

- Pimentel, D., and T.W. Patzek. 2005. "Ethanol Production Using Corn, Switchgrass, and Wood; Biodiesel Production Using Soybean and Sunflower." *Natural Resources Research* 14 (1): 65-76.
- Pimentel, D., A. Marklein, M.A. Toth, M.N. Karpoff, G.S. Paul, R. McCormack, J. Kyriazis, and T. Krueger. 2009. "Food versus Biofuels: Environmental and Economic Costs." *Human Ecology* 37(1): 1-12.
- Pimentel, D., and R. Lal. 2007. "Biofuels and the Environment." *Science* 317(5840): 897-898.
- Powers, S.E. 2007. "Nutrient Loads to Surface Water from Row Crop Production." *International Journal of Life Cycle Assessment* 12(6): 399-407.
- Pradhan, A., D.S. Shrestha, J. Van Gerpen, and J. Duffield. 2008. "The Energy Balance of Soybean Oil Biodiesel Production: A Review of Past Studies." *Transactions of the ASABE* 51(1): 185-194.
- Rapier, R. 2007. "Ethanol/Alternative Fuel." Frequently Asked Questions. R-Squared Energy Blog. Accessed December 2011. Available at <http://www.consumerenergyreport.com/2007/08/18/>.
- Renewable Fuels Association. 2010a. "Renewable Fuel Standard Program (RFS2)-2010 and Beyond." Accessed September 2011. Available at <http://www.ethanolrfa.org/pages/RFS-2-EMTS-Information>.
- _____. 2010b. "Historic U.S. Fuel Ethanol Production." Accessed September 2011. Available at <http://www.ethanolrfa.org/pages/statistics>.

- _____. 2011. "Federal Tax Incentives: VEETC." Accessed January 2012. Available at <http://www.ethanolrfa.org/pages/federal-tax-incentives-veetc>.
- Ribaudo, M.O. 1992. "Options for Agricultural Nonpoint Source Pollution Control." *Journal of Soil and Water Conservation* 47: 42-46.
- Rister, E. M., R. D. Lacewell, A. W. Sturdivant, T. Lee, R. Srinivasan, B. Narashimhan, C. Wolfe, D. Waidler, D. Andrew, M. Ernst, J. Owens, B. Lesikar, L. F. Gregory, A. Jones, B. L. Harris, E. K. Seawright, and S. R. Yow. 2009. *NCTXWQ Project: Evaluating the Economics of Best Management Practices for Tarrant Regional Water District's Cedar Creek Reservoir*. College Station, TX: Texas Water Resources Institute, TR-357, January.
- Rooney, W.L. 2011. Associate Professor, Department of Soil and Crop Sciences. Texas A&M University, College Station, TX. Personal Communication. June 24, 2011.
- Santhi, C., R. Srinivasan, J.G. Arnold, and J.R. Williams. 2006. "A Modeling Approach to Evaluate the Impacts of Water Quality Management Plans Implemented in a Watershed in Texas." *Environmental Modeling & Software* 21: 1141-1157.
- Schmer, M. R., K.P. Vogel, R.B. Mitchell, and R.K. Perrin. 2008. "Net Energy of Cellulosic Ethanol from Switchgrass." *Proceedings of National Academy of Sciences* 105(2): 464-469.

Seawright, E.K., R.D. Lacewell, N.C. Adusumilli, C.R. Taylor, and M. E. Rister. 2010.

“Net Energy Balance for Ethanol from Irrigated Corn in the High Plains of Texas.” Accessed December 2011. Available at <https://sites.auburn.edu/academic/ag/group/bioenergy>.

Secchi, S., P.W. Gassman, M. Jha, L. Kurkalova, H.H. Feng, T.Campbell, and C.L.

Kling. 2007. “The Cost of Cleaner Water: Assessing Agricultural Pollution Reduction at the Watershed Scale.” *Journal of Soil and Water Conservation* 62(1): 10-21.

Seedland, Inc. 2012. “Ryegrass.” Accessed January 2012. Available at www.seedland.com.

Shapouri, H., J.A. Duffield, and M. Wang. 2002. *The Energy Balance of Corn Ethanol: An Update*. Washington, DC: U.S. Department of Agriculture, Agricultural Economic Report No. 813, January.

Simpson, T.W., A.N. Sharpley, R.W. Howarth, H.W. Pearl, and K.R. Mankin. 2008.

“The New Gold Rush: Fueling Ethanol Production While Protecting Water Quality.” *Journal of Environmental Quality* 37(2): 318-324.

Stock Seed Farms. 2012. “Sudan Grass.” Accessed January 2012. Available at www.stockseed.com.

Swanton, C.J., S.D. Murphy, D.J. Hume, and D.R. Clements. 1996. “Recent Improvements in the Energy Efficiency of Agriculture: Case Studies from Ontario, Canada.” *Agricultural Systems* 52: 399-418.

- Taylor, C.R. 1978. *National Economic Impacts of Using Crop Residues and Grain to Produce Alcohol*. Washington, DC: U.S. Congressional Office of Technology Assessment, Unnumbered Report.
- Taylor, C.R. 1993. "Policy Evaluation Exercises with AGSIM." In: C.R. Taylor, K.H. Reichelderfer, and S.R. Johnson (Eds). *Agricultural Sector Models for the United States: Descriptions and Selected Policy Applications*. Ames, IA: Iowa State University Press.
- Taylor, C.R., H.A. Smith, J.B. Johnson, and T.R. Clark. 1994. "Aggregate Economic Effects of CRP Land Returning to Production." *Journal of Soil and Water Conservation* 49(5): 325-328.
- Taylor, C.R., and R.D. Lacewell. 2009a. "Aggregate Economic Effects of Corn Ethanol and Soy-Based Biodiesel Production." BioEnergy Policy Brief, BPB 070209. Accessed August 2011. Available at <https://sites.auburn.edu/academic/ag/group/bioenergy>.
- _____. 2009b. "Effects of Corn Ethanol and Soy-Based Biodiesel Production on Soil Erosion and Return of Conservation Reserve Program Land to Crop Production." BioEnergy Policy Brief, BPB 070409. Accessed August 2011. Available at <https://sites.auburn.edu/academic/ag/group/bioenergy>.
- Taylor, C.R., and M.M. Taylor. 2009c. "A Brief Description of AGSIM: An Econometric-Simulation Model of the Agricultural Economy Used for Biofuel Evaluation." BioEnergy Policy Brief, BPB 070109. Accessed August 2011. Available at <https://sites.auburn.edu/academic/ag/group/bioenergy>.

- Texas AgriLife Extension Service. 2011. *2011 Texas Agricultural Custom Rates*.
- Texas AgriLife Extension Service. College Station, TX.
- Thomas, M.A., S.M. Asce, B.A. Engel, and I. Chaubey. 2009. "Water Quality Impacts of Corn Production to Meet Biofuel." *Journal of Environmental Engineering* 135(11): 1123-1135.
- Tilman, D., J. Hill, and C. Lehman. 2006. "Carbon-Negative Biofuels from Low-Input High-Diversity Grassland Biomass." *Science* 314(5805): 1598-1600.
- Tilman, D., K.G. Cassman, P.A. Matson, R. Naylor, and S. Polasky. 2002. "Agricultural Sustainability and Intensive Production Practices." *Nature* 418: 671-677.
- Toman, M., J. Griffin, and R.J. Lempert. 2008. "Impacts on U.S. Energy Expenditures and Greenhouse-Gas Emissions of Increasing Renewable-Energy Use." Santa Monica, CA : RAND Corporation, RAND Technical Report TR-384-1-EFC, June.
- Trostle, R., D. Marti, S. Rosen, and P. Westcott. 2011. *Why Have Food Commodity Prices Risen Again?* Washington, DC: Economic Research Service, WRS-1103, January.
- U.S. Census Bureau. 2005. "Statistical Abstracts." Accessed December 2011. Available at <http://www.census.gov/compendia/statab>.
- U.S. Congress. 2007. *Energy Independence and Security Act of 2007*. Washington, DC: H.R.6, 110th Congress, 1st session.

U.S. Department of Agriculture. 2005. *Energy Use in Agriculture. U.S. Agriculture and Forestry Greenhouse Gas Inventory 1990-2005*. Washington, DC: U.S.

Department of Agriculture, Chapter 5.

_____. 2011. *USDA Agricultural Projections to 2020*. Washington, DC: U.S.

Department of Agriculture, Office of the Chief Economist, Long-term

Projections Report OCE-2011-1, June.

U.S. Department of Energy. 2007. “Ethanol: The Complete Energy Life Cycle Picture.”

Accessed January 2012. Available at <http://www.transportation.anl.gov/pdfs/TA/345.pdf>.

_____. 2011. “National Ethanol Feedstock Resource.” Accessed September 2011.

Available at http://www.afdc.energy.gov/afdc/ethanol/feedstocks_resources_national.html.

U.S. Energy Information Administration. 2009. “Renewable Energy Consumption:

Industrial and Transportation Sectors, 1949-2009.” Data. U.S. EIA. Accessed August 2011. Available at <http://www.eia.gov/renewable/data>.

_____. 2010. “U.S. Imports of Crude Oil and Petroleum Products.” Data. U.S. EIA.

Accessed February 2010. Available at <http://www.eia.gov/petroleum/>.

U.S. Environmental Protection Agency (EPA). 2010. *EPA Finalizes Regulations for the National Renewable Fuel Standard Program for 2010 and Beyond*.

Washington, DC: Office of Transportation and Air Quality, EPA Report 420-F-10-007, January.

- Ugarte, D.G., B.C. English, C.M. Hellwinckel, R. J. Menard, and M.E. Walsh. 2007. *Economic Implications to the Agricultural Sector of Increasing the Production of Biomass Feedstocks to Meet Biopower, Biofuels, and Bioproduct Demands*. Knoxville, TN: The University of Tennessee, Research Series No. 08-01, June.
- Vinas, Tonya. 2009. "Sustainable Ethanol Industry Rapidly Forming in U.S." Accessed December 2011. Available at http://www.industryweek.com/articles/sustainable_ethanol_industry_rapidly_forming_in_u-s-_18847.aspx
- Webster, E.P., and D.R. Shaw. 1996. "Impact of Vegetative Filter Strips on Herbicide Loss in Runoff from Soybean (*Glycine max*).” *Weed Science* 44(3): 662-671.
- Wright, L. 2007. *Historical Perspective on How and Why Switchgrass was Selected as a "Model" High-Potential Energy Crop*. Oak Ridge, TN: Oak Ridge National Laboratory Report Prepared for the U.S. Department of Energy Under Contract DE-AC05-00OR22725, Report No. ORNL/TM-2007/109, February.
- Yacobucci, B.D. 2012. *Biofuel Incentives: A Summary of Federal Programs*. Washington, DC: Congressional Research Service, Report No. R40110, June.
- Young, B. 2008. "Ethanol's Impact on Food, Gasoline Prices.” *Farm Bureau* 87(8): 2. Accessed August 2011. Available at <http://www.fb.org/assets/files/fbn/2008/>.
- Yuan, Y., and R.L. Binger. 2002. *Assessment of Best Management Practices for Water Quality Improvement for the Deep Hollow Watershed in Mississippi Delta MSEA Project Using AGNPS*. Washington, DC: U.S. Department of Agriculture, Research Report No. 28, January.

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